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Carbon pricing reform and expectations Evidence from French manufacturing, 2005-2019

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Carbon pricing reform and expectations*
Evidence from French manufacturing, 2005-2019

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Abstract

This paper investigates the effects of the 2014 French carbon tax reform on plant manufacturing energy use patterns and employment outcomes using a linear panel event study specification spanning fifteen years. The analysis exploits low-carbon electricity use to construct a proxy for exposure and expected exposure to increasingly higher carbon pricing, as the rate is set to reach €100 per tCO_2 by 2030. A 10 percentage point (pp) increase in exposure is significantly associated with a 1.9 pp increase in the electricity share of fuel use, along with a 4.39% decrease in total energy use. Exposure is not associated with a change in electricity use levels, but is weakly associated with a drop in fossil fuel use: the electricity to fossil fuel use ratio increases by around 4.86 percent. Exposure is also weakly associated with job losses.

Keywords: Carbon tax, Policy Evaluation, Manufacturing, France, Expectations
JEL Codes: Q48, Q52, L6, D84

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1 Introduction

Whereas carbon emissions are a by-product of valuable economic activity since the Industrial Age, their accumulation in the atmosphere is the root cause of global warming (Intergovernmental Panel on Climate Change, 2018; Colmer et al., 2022). Recognizing the adverse risks and impacts of climate change on current and future generations, signatories of the Paris Agreement pledged to pursue efforts to limit global warming to below 2°C relative to pre-industrial levels. Such efforts entail reducing economic dependence on carbon-intensive activities. As the consumption of fossil fuels incurs an unintended cost to the environment and society, a 2014 tax reform in France introduced an explicit price on carbon to motivate polluters to lower their emissions. The 2015 Energy Transition for Green Growth Act (LTECV, *Loi de transition énergétique pour la croissance verte*) additionally programs the tax to reach €100 per tCO_2 by 2030.

A predictable and rising carbon price promotes an orderly transition to a low-carbon economy by increasing the financial costs of carbon-intensive activities to the benefit of cleaner activities that do not contribute to global warming (OECD and World Bank Group, 2015). As investments in industry typically have long-term horizons, investors need to form expectations about carbon prices over the entire lifetime of the investment (OECD, 2020). Hence setting a long-term trajectory of the French carbon price helps manage expectations regarding the future relative profitability of fossil fuel consumption, which can considerably discount the profitability of ongoing consumption. In parallel, a carbon price allows polluters to decide on the least-cost abatement options at their disposal when facing the additional cost on production. Holding all else equal the objective of the carbon price is to eliminate its tax base: it lowers the financial incentive to burn fossil fuels as it becomes too costly to continue to do so. When feasible, businesses can switch away from dirty assets and technologies towards cleaner alternatives. In short and from a business perspective, the economic costs of a carbon price would largely rely on both the carbon intensity of production and on the ability to substitute between energy inputs.

Accordingly, this paper empirically investigates the effects of the carbon tax reform on energy consumption choices and on employment outcomes in French manufacturing. Using a linear panel event study Differences-in-Differences (DiD) approach spanning fifteen years (2005-2019), findings reveal that a 10 percentage point (pp) increase in exposure to carbon pricing is statistically associated with a 1.9 pp increase in the share of electricity use, along by a 4.39% drop in total energy use. While evidence does not reveal a change in electricity use levels, it does suggest a drop in fossil fuel use levels albeit statistical significance is low. Moreover a 10 pp increase in exposure increases the electricity to fossil fuel use ratio by 4.86% at the 5 percent level of significance. Exposure to carbon pricing is also weakly associated with lower employment outcomes. Simply put, exposure and expectations of increasingly higher exposure to carbon pricing in French manufacturing likely motivated the most highly exposed plants to lower their fossil fuel consumption, thereby also lowering their overall energy use levels relative to cleaner plants since carbon-intensive fuels represent a large share of their energy mix. As the most exposed plants shed some of their carbon-intensive activities, job opportunities associated with such activities were likely reduced as well. Finally, this response to the carbon tax reform increases the reliance of plants on electricity power for continued production.

While understanding the link between energy use choices, employment outcomes and environmental regulation is important for efficiency and distributional concerns, the empirical literature on the effects of carbon pricing is relatively scarce. Accordingly, the principal contribution of this paper, by exploiting the peculiarities of the French energy mix and tax system, is to empirically investigate the environmental and employment impacts of exposure and expected future exposure to carbon pricing on French industry, abstracting from imposing any restrictions on the economy. The identification strategy relies on the fact that electricity power is a low-carbon source of energy in France and is therefore not subject to the excise duty on carbon emissions. On the other hand, fossil fuel use is subject to the tax. As a result, exposure to carbon pricing is correlated with the use of carbon-intensive fuels relative to electricity use. The main dependent variable represents the estimated growth in total energy costs if the programmed 2030 tax rate applied to carbon emissions from fossil fuel use before the reform. As necessary for identification, the estimated growth in energy costs and the share of electricity use have a straight-line negative relationship, meaning that the former can serve as a proxy for exposure and expected future exposure to carbon pricing. Importantly, graphical results indicate a lack of pre-trends until the year prior the reform.

The next section briefly overviews the related empirical literature . Section (3) describes the institutional background in France and Section (4) presents the data sources, the key variable used in the analysis and summary statistics. Section (5) describes the empirical strategy and Section (6) details the empirical findings and robustness checks. Section (7) provides a discussion of results. The last section concludes.

2 Related literature

Exploiting the idiosyncrasies of the French energy mix and tax system, this paper contributes to the empirical literature that exploits energy consumption as a measure of carbon policy stringency and identification approach. In a similar vein, Germeshausen (2020) utilizes variations in ex-ante treatment intensities, based on both allowance emission prices and heat rates, to identify the impact of the European Emission Trading Scheme (EU-ETS) on fossil fuel power plants in Germany. An increase in plant carbon cost of €1 per megawatt (MWh) due to the cap-and-trade system is associated with a reduction in fuel input of around 0.3% on average and holding production levels constant. Similarly Ahmadi, Yamazaki, and Kabore (2022) identify the effects of the carbon tax in British Columbia (BC) by triple DiD utilising the average pre-policy emission intensity as a proxy for the size of policy exposure. They conclude that the carbon tax reduced plant-level manufacturing emissions by 4% relative to plants outside BC, along with a positive effect on output (1.8%) and a larger negative effect on emission intensity (6%). Moreover exploiting pre-reform levels of GHG and trade intensities at the industry-level, Yamazaki (2017) finds that the revenue-neutral BC carbon tax generated an overall annual increase (0.74%) in employment.

More broadly, this paper contributes to the literature on the environmental and economic effects of energy and green market-based regulations. Market-based regulations encourage a change in behavior through market signals rather than through explicit directives regarding pollution control levels or methods (Portney and Stavins, 1998). Using French micro-data and a matching DiD approach, Colmer et al. (2022) conclude that the EU-ETS reduced carbon emissions by 8 to 12% during trading Phase II via targeted investments in cleaner production processes, with no evidence of detrimental effects on economic performance nor of input substitution towards (cleaner) electricity. Moreover and taking a synthetic control approach, both Leroutier (2022) and Andersson (2019) uncover a negative relationship between carbon taxes and carbon emissions in the United Kingdom (UK) power sector and Swedish transport sector, respectively. In UK manufacturing the carbon tax caused a strong reduction in energy intensity (18.1%) and in (carbon-intensive) electricity use (22.6%) with no evidence of a negative effect on employment, revenue or plant exit (Martin, de Preux, and Wagner, 2014).

This paper more specifically looks at the effects of carbon excise duties on business behavior in France. Both Marin and Vona (2021) and Dussaux (2020) utilize an average weighted energy cost specification to proxy for carbon tax rates in French manufacturing. At the firm-level, Dussaux finds that a 10% increase in energy costs is associated with a decline in energy use (5.9%) and a larger decline in carbon emissions (9.2%), driven by a reduction in fossil fuels (6.5%) and a statistically insignificant effect on electricity use. Dussaux also uncovers a reduction in jobs (2.2%), although net employment effects at the industry-level become insignificant after accounting for worker reallocation from energy-intensive to energy-efficient firms. At the plant-level and similarly, Marin and Vona (2021) conclude that a 10% increase in energy costs reduces energy use by 5.2% and carbon emissions by 11.4%, along with a smaller negative impact on employment (0.8%) and on Total Factor Productivity (1.3%). With respect to employment effects more generally, the literature finds that carbon prices tend to cause a reallocation of employment (a shift of jobs from one sector to another) rather than a net gain or loss in jobs (Resources for the Future, 2020).

Finally, this paper contributes to the empirical literature on agent expectations and environmental policy design in driving empirical findings. As investment and production decisions typically have long-term horizons in industry, businesses need to form expectations about the trajectory of carbon prices (OECD, 2020). Predictable and increasing carbon prices over time supports and promotes near-term low-carbon investment decisions and avoids lock-in of carbon-intensive assets, thereby lowering the costs of decarbonization (OECD and World Bank Group, 2015). Accordingly, forward-looking consumers expecting a change in environmental regulations anticipate and prepare for future higher compliance costs (Coglianese et al., 2017, Rittenhouse and Zaragoza-Watkins, 2018).

3 Institutional background

The taxation of energy use (including electricity) conforms to the European Union (EU) framework for energy product taxation as defined in Council Directive 2003/96/EC that sets minimum rates. Historically the purpose of taxing energy use in France was to raise a stable stream of revenues, as opposed to changing behavior through a price signal (Chiroleu-Assouline, 2015). Accordingly, excise duties on fossil fuels used for stationary engines were fixed until the introduction of a carbon tax in 2014. Energy tax revenues reached almost 2% of GDP by 2018, although representing only 4.94% of total compulsory levies (Cours des Comptes, 2019).

The successful implementation of a national carbon tax in 2014 followed two failed attempts in 2000 and in 2009. The 2000 proposal included electricity as a tax base and was invalidated by the Constitutional Council for being environmentally ineffective, among other reasons. Moreover while the French parliament voted to introduce a carbon tax in 2009 for a second time, the proposal was again invalidated by the Council 11 days later on the grounds of violating the principle of tax equality (Ministry of the Ecological Transition, 2021). In distinction to the 2000 and 2009 attempt, the 2014 carbon tax not only does not apply to electricity, a low-carbon source of energy in France, but also was introduced as a re-calculation of existing energy taxes on fossil fuels proportional to their carbon content.

A carbon tax was incorporated in the taxation of fossil fuels at a starting rate of €7 per tCO_2 in April 2014. It was expected to gradually increase to €22 per tCO_2 by 2016 (PLF, 2014). A couple months before signing the Paris Agreement in December 2015, the government additionally introduced the Energy Transition for Green Growth Act (LTECV, *Loi de transition énergétique pour la croissance verte*). Article 1 of the LTECV sets a long-term trajectory of the carbon tax rate to a rate of €100 per tCO_2 by 2030. The objective in setting the long-term trajectory of the tax was to provide a clear and predictable price signal to guide and steer medium to longer-term investments and consumption towards low-carbon alternatives. Graph (1) presents the expected and actual trajectory of the french carbon tax through 2030. Nevertheless in 2019 following the yellow vests protests against higher automobile fuel prices, among other policy measures, the government froze the carbon tax rate to its 2018 rate (€44.6 per tCO_2). The 2030 trajectory of the rate to €100 per tCO_2, as detailed in the LTECV, was left unchanged.

Preferential energy tax treatment - in the form of rate reductions and tax exemptions - are largely based on the size and purpose of consumption. As a general rule the largest consumers, such as energy-intensive firms[1], pay the lowest excise duties on energy. To avoid double carbon taxation, energy-intensive firms that also participate in the EU-ETS are not liable to the carbon excise duty. Energy used in specific industrial processes are tax exempt. They include metallurgical, electrolysis and chemical reduction processes and the manufacturing of other non-metallic mineral products (NACE

[1] An "energy-intensive" firm, as defined in Article 17 of the Directive 2003/96/EC of 27 October 2003, is one where either 1) the purchases of energy products and electricity amount to at least 3.0% of its production value, or 2) the national energy tax payable amounts to at least 0.5 % of its added value.

Rev.2 2-digit industry 23). Activities that benefit from a tax exemption in chemical reduction processes are determined at the NACE Rev.2 4-digit industry code level, underlining the potential wide heterogeneity in tax treatment at a very granular level in industry. Preferential tax treatment weakens the carbon price signal and incentives to mitigate polluting behavior (Chiroleu-Assouline, 2015).

Figure 1: Expected versus actual carbon tax rate on fossil fuel use in France

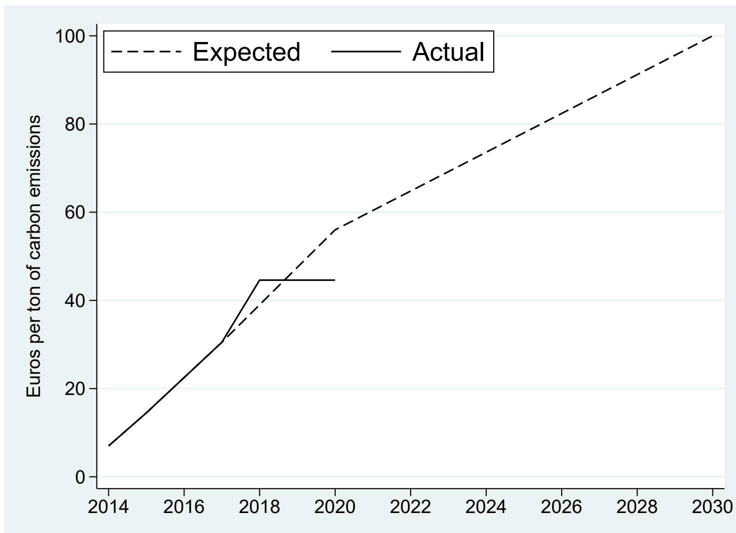


Figure 1 shows both the actual carbon tax rate applied to fossil fuels in France, as well as the expected rates as detailed in yearly Budget Acts and in the 2015 Energy Transition for Green Growth Act (LTECV). In 2019 following the yellow vests protests, the government froze the actual rate to its 2018 rate. Sources: PLF, 2014, PLF, 2015 and PLF, 2018.

4 Data

4.1 Data sources

The final panel is composed of manufacturing plants located in metropolitan France from 2005 to 2019. The unbalanced panel includes 5 000 to 8 000 plants per year. Balancing the panel after omitting EU-ETS participants drops the number of observations to 834 plants per year. It merges three different data-sets.

The Eacei (*Enquête sur les consommations d'énergie dans l'industrie*) database[2] provides survey data on energy consumption and expenditure by fuel and in aggregate, as well as employment information. 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. Stratification is based on activity classification and employment

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

level. Each year, surveyed plants provide information on purchased quantities of fuels in metric base units, as well as their cost value in euros (excluding any deductible value-added tax), for the prior calendar year. The monetary value of total energy costs is also provided in the Eacei database. The response rate to the survey is relatively high, at 85% in 2011 and 90% in 2014.

Electricity use is expressed in megawatt-hours (MWh) and converted into tons of oil equivalents (toe). The different types of fossil fuels are also converted into toe units. Employment represents the number of individuals employed as at December 31st in the plant. For electricity and natural gas, total cost includes the cost of transport and distribution. Under the assumption that electricity and fossil fuels rely on different types of capital equipment, the balanced panel omits plants that only consume electricity or fossil fuels throughout all years. On average, fossil fuels and electricity use represent around 97% of total energy use in the Eacei database.

The BIC-RN database provides data from French corporate tax returns, which firms are obligated to complete. Firm-level variables, notably the monetary value of total sales, come from income statements. While a plant is identified by its 14-digit plant identifier number (Siret) in France, the first 9 digits of the Siret is the plant's firm identifier (Siren).

Finally, data on European carbon market (EU-ETS) participation comes from the European Union Transaction Log (EUTL), and more specifically from Abrell (2022). The EUTL provides data on participating plants in the carbon market, including compliance status and verified emissions. As it only details the firm identifier of the plant, EU-ETS participation status is provided at the firm-level in the panel. This means that if a multi-plant firm possesses at least one plant identified as an EU-ETS participant, then all its plants (surveyed in Eacei) are flagged as participants. A firm is identified as not participating in the carbon market in a given year if it has both a missing compliance status and a missing amount of verified emissions. Around 7% of plants in the unbalanced panel are flagged as EU-ETS participants across all years, and this percentage increases to 19% after balancing the panel (with 1 069 plants per year). The final balanced panel omits EU-ETS participants as they are likely not liable to the carbon excise duty in France, amounting to 834 plants per year over fifteen years.

4.2 Construction of main dependent variable: exposure to carbon pricing

The Energy Transition for Green Growth Act sets a carbon tax rate of €100 per tCO_2 for 2030. Abstracting from application of preferential tax treatment, a forward-looking manager of plant *i* can estimate the full additional carbon cost she could expect to face in 2030, holding carbon emissions constant[3]. The estimated growth in total energy

[3]
$$\text{Carbon costs in } 2030_{i,year} = \sum_{\text{Fossil fuels}} (tCO_2)_{i,year} \times €100 \text{ per } tCO_2$$

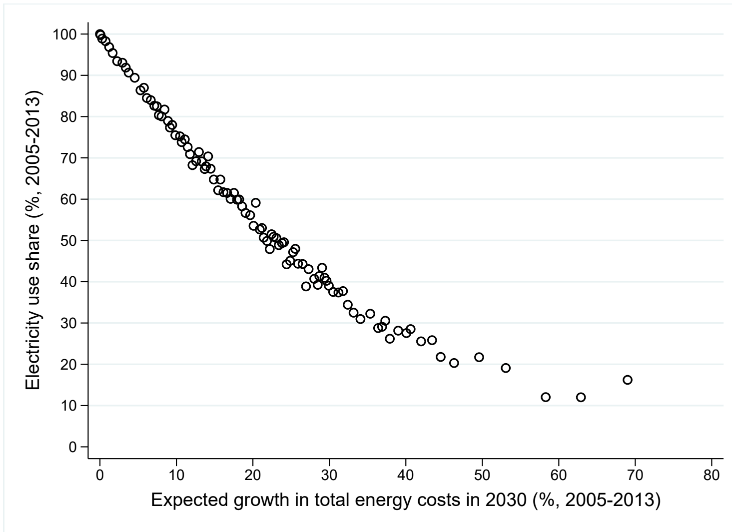
To calculate tons of carbon emissions (tCO_2), emissions factors listed in Table (D1) are applied to each fossil fuel (natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel) according to their respective carbon content.

costs - Equation (1) - illustrates by how much costs increase if a carbon tax of €100 per tCO_2 applied to carbon emissions from fossil fuel use, absent any change in polluting behavior. Equation (1) is set at its pre-reform (2005-2013) average in the empirical model.

$$\text{Growth in total energy costs}_{i,<2014} = \Big[\text{(Total energy costs + Carbon costs in 2030)} \\ -\text{(Total energy costs)}\Big]_{i,<2014} \Big/ \text{(Total energy costs)}_{i,<2014} \times 100 \tag{1}$$

The main takeaway from Figure (1) is that the estimated growth in total energy costs can serve as a proxy for exposure and expected exposure to carbon pricing. The figure illustrates the almost straight-line negative relationship between the variable and electricity use, where the latter is not subject to the excise duty on carbon. A plant that consumes electricity at a very large share of its energy use mix does not estimate considerable growth in total energy costs because of its low exposure to carbon pricing, and abstracting from shorter-term price volatility. On the other hand, a plant consuming roughly half of its energy mix as electricity can estimate around a 23% increase in energy costs due to higher expected carbon costs.

Figure 2: Correlation between electricity use share (%) and the estimated growth in total energy costs by 2030 (%)



Note: Figure (2) presents a binned scatter-plot, where the y-axis refers to the following Equation

$$\text{Electricity use share}_{i,<2014} \equiv \left[\frac{\text{Electricity use}}{(\text{Electricity use} + \text{Fossil fuel use})}\right]_{i,<2014} \times 100$$

and the x-axis to Equation (1). Electricity and fossil fuel use are expressed in tons of oil equivalents (toe).

4.3 Descriptive statistics

Table (A1) presents descriptive statistics for the first year of the panel (2005). On average plants consume a large share of electricity of energy use, and can expect a 21% growth in energy costs if a carbon tax of €100 per tCO_2 applied to fossil fuel use, based on calculations provided in the previous section. The sample is largely dominated by several industries: the manufacturing of chemicals, other non-metallic minerals and fabricated metal products represent two-fifths of the entire panel. Note that including EU-ETS participants in the panel increases the average expected growth to around 30% and average total energy use to around 11 thousand toe, underlining how participants in the European carbon market are particularly carbon and energy-intensive.

Table (A2) presents descriptive statistics by exposure level based on the plant's estimated growth in total energy costs, Equation (1), as shown in the equation below.

$$\text{DExposure}_{i,<2014} = \begin{cases} 1 \equiv \text{high, if Growth in total energy costs}_{i,<2014} > \text{p50} \\ 0 \equiv \text{low, otherwise} \end{cases} \quad (2)$$

Plants with relatively low exposure consume larger amounts of electricity relative to fossil fuels since electricity is not subject to the carbon tax. Plants with higher exposure consume more energy both in quantity and in costs on average, albeit have less employees and generate slightly less firm-level revenues than plants with lower exposure. Industry composition across both groups of plants is broadly similar, albeit more concentrated - particularly with regards to the manufacturing of chemicals and other non-metallic mineral products - among the higher exposed plants.

5 Empirical strategy

With the exception of plants that participate in the European cap-and-trade system and plants that exclusively consume electricity, all energy consumers face the carbon excise duty at different levels of exposure contingent on energy use and their eligibility to preferential tax treatment. Hence there is a lack of a clear control group of plants for identification in a standard DiD strategy with binary treatment.

As a result, the empirical strategy exploits a continuous DiD specification, whereby the estimated growth in total energy costs - Equation (1) - proxies for exposure and expected future exposure to increasingly stringent carbon pricing. The use of a percentage accommodates for significant differences in energy use levels between plants. The use of the pre-reform average minimizes the risk of capturing unobserved confounders correlated with both the policy and the outcome.

$$\text{Exposure}_{i,<2014} \equiv \text{Growth in total energy costs}_{i,<2014} \tag{3}$$

The event study specification is Equation (5). It includes a set of 15 dummy variables equalling one for each year in the panel, $\sum_{year=2005}^{2019} \lambda_{year}$. The coefficient of interest, β_1, interacts the year dummies with the main dependent variable, $\text{Exposure}_{i,<2014}$. Outcomes of interests include the electricity use share[4], the total energy use level, the fossil fuel and electricity use level, the electricity over fossil fuel use ratio and the employment level.

$$\begin{aligned} y_{i,year} = \alpha_i + \sum_{year=2005}^{2019} \beta_1 (\lambda_{year} \times \text{Exposure}_{i,<2014}) + \sum_{year=2005}^{2019} \Big[\gamma(\lambda_{year} \times \text{Industry}_i) \\ + \mu (\lambda_{year} \times \text{Region}_i) + \eta (\lambda_{year} \times \chi_{i,2005}) \Big] + \varepsilon_{i,year} \end{aligned} \tag{5}$$

4

$$\text{Electricity use share}_{i,year} \equiv \left[\frac{\text{Electricity use}}{(\text{Electricity use} + \text{Fossil fuel use})} \right]_{i,year} \times 100 \tag{4}$$

To help account for omitted variable bias, the event study results include plant dummies (α_i) that capture plant-specific time-invariant characteristics. It also captures granular (4-digit NACE Rev. 2) industry-specific yearly shocks and trends (γ) that could be correlated with both the outcome and exposure to carbon pricing. Regional-level trends that could explain differences in outcomes are captured through coefficient μ. Coefficient η accounts for additional size effects: $\chi_{i,2005}$ includes plant total energy consumption, plant employment, as well as firm-level total sales set at their 2005 levels to minimize correlation with the policy in the post-reform years. Coefficient $\varepsilon_{i,year}$ is the error term. Total energy use and employment are omitted as controls in the regression equation when used as outcome variables.

$$
\begin{aligned}
y_{i,t} = \alpha_i + \beta_1(\text{Exposure}_{i,<2014} \times \text{Post}_t) + \gamma(\text{Post}_t \times \text{Industry}_i) \\
+\mu(\text{Post}_t \times \text{Region}_i) + \eta(\text{Post}_t \times \chi_{i,2005}) + \varepsilon_{i,t}
\end{aligned}
\tag{6}
$$

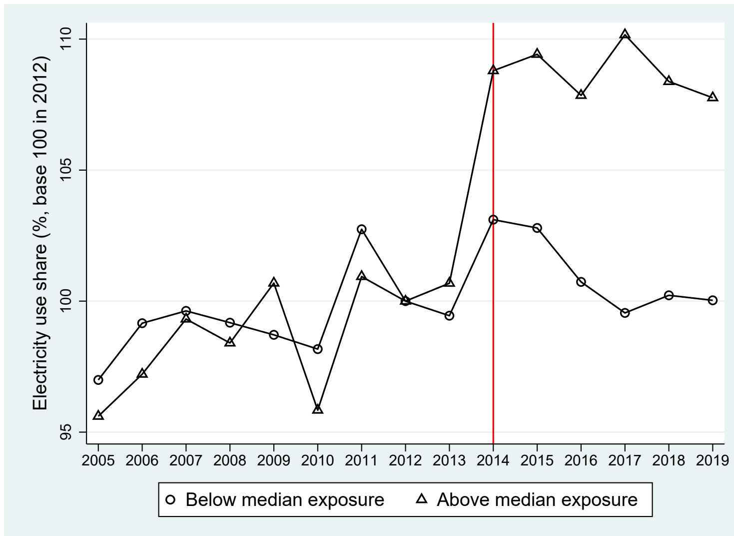
Average effects of exposure to carbon pricing are estimated using Equation (6). The year dummies are replaced with a time dummy, Post_t equalling one for the post-reform period. The model estimates the average effect of higher exposure to carbon pricing in the post-reform period (t = 1: 2014-2019) relative to pre-reform (t = 0: 2005-2013) on the outcome y of plant i in time t. Average effects are presented in a stepwise procedure with each additional independent variable added to the regression equation.

5.1 Identification

The principal identification assumption is that the trajectory of relatively more exposed plants would have continued to follow the trajectory of the relatively less exposed plants in the absence of the carbon tax reform. The event study specification detailed in Equation (5) serves as an indirect test of the presence of differential pre-trends, where flat and non-statistically significant effects in the pre-reform years would support the common trends assumption. To further motivate this identifying assumption, Figure (3) presents electricity use share average trends of the relatively highly exposed plants compared to the less exposed, as defined in Equation (2).

Figure (3) shows that the trajectory of both groups were broadly similar until 2014 - the year the carbon tax was introduced - when the electricity use share among the most exposed plants visibly increases relative to the least exposed by several percentage points and relative to 2012. Pre-reform trajectories also look broadly similar in Figures (A1a) - (A1e) for the additional outcomes of interest. They suggest that the increase in the electricity use share is less driven by an increase in electricity use levels than by a relative decrease in total energy use among the most exposed. Figure (A1d) notably highlights a relative increase in the electricity to fossil fuel use ratio among the most exposed plants. A simple t-test of the pre-reform average trends between the two groups are not statistically significant from zero for all outcomes, with the exception of Figure (A1b).

Figure 3: Parallel trends - electricity use share (%)



Note: Exposure level is determined in Equation (2). The electricity use share refers to Equation (4) in Footnote (4). Average trends are indexed to year 2012.

In parallel, identification also necessitates that were no other shock that occurred at the same time as the introduction of the carbon tax and that would be correlated with the effect of differential exposure to the policy on the outcome. This threat to identification is discussed in Section (7). Moreover, identification more generally relies on the assumption that industry expects higher carbon stringency in the future, abstracting from shorter-term price volatility[5]. Risk averse and forward-looking industry decision-makers have an incentive to make production and investment decisions to lower immediate and future carbon costs

6 Results

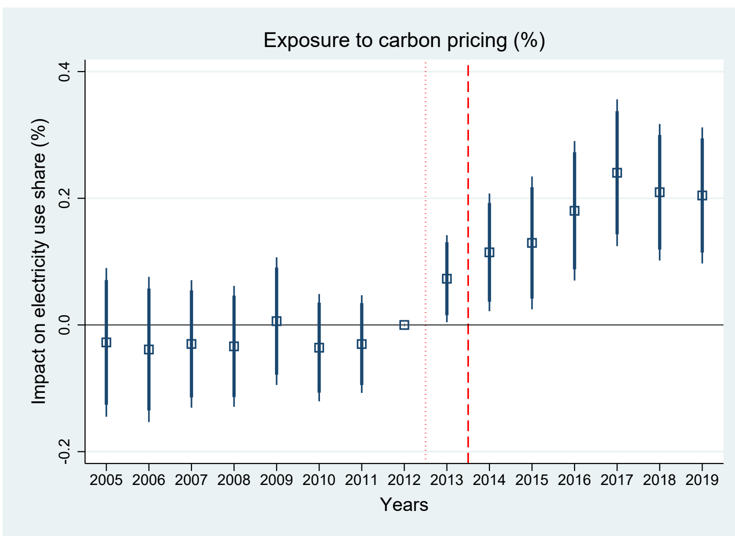
Figure (4) indicates that an increase in exposure to carbon pricing is significantly associated with an increase in the electricity use share and at a level that increases linearly

[5]In the fall of 2009, Anderson et al. (2011) interviewed over 800 manufacturing firms in six European countries on their climate change corporate policies. While the focus of the interview was on EU-ETS participants, it is worth noting that French firms expected both the highest carbon tax rate (around €50 per tCO_2) for 2020, as well as the lowest expected energy price, among all other countries. They also find that french firms expected significantly stronger-than-average impacts of future climate policies, after controlling for industrial composition. They note that interviews occurred when the French parliament was attempting to introduce an excise duty on carbon emissions, which could partly explain expectations (see Section (3). They also posit that the low expectations on energy price increases may be due to the high share of nuclear energy in the electricity mix in France. More broadlly, these findings help motivate the assumption that industry managers expect higher future carbon costs in the future.

from 2013 to around 2017 before stabilizing the last two years of the panel. In parallel, the figure presents a lack of evidence of differential pre-trends up to the year prior the reform.

Moreover figures (5) and (B1) together suggest that the increase in the electricity use share is likely driven by a relative drop in total energy use during the post-reform years, as opposed to an increase in electricity use levels. The event study estimates in the latter figure are not statistically significant from zero across all years. Figures (B2) and (B3) further suggest that the drop in total energy use among the relatively more exposed plants is driven by a relative drop in fossil fuel use, thereby generating an increasing positive association between exposure and the electricity to fossil fuel use ratio in the post-reform years, albeit pre-trends are less flat and post-reform effects less linear and less often statistically significant.

Figure 4: Event study DiD effect of exposure to carbon pricing (%) on the electricity use share (%)

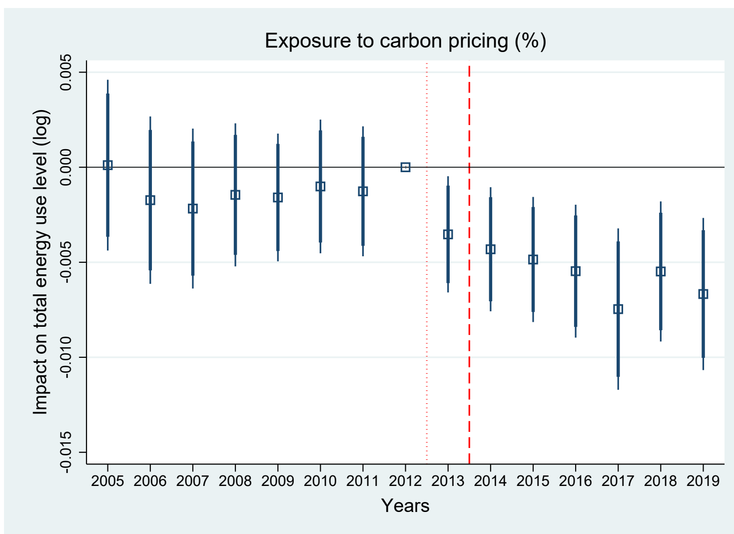


Note: Exposure to carbon pricing is proxied by the estimated growth in total energy costs, or Equation (1). The electricity use share refers to Equation (4) in Footnote (4). Figure (4) shows results from Equation (5). The final balanced panel omits participants in the European carbon market, and includes 834 plants per year. Standard errors are clustered at the plant-level. Confidence intervals are set at the 10% level (thick line) and at the 5% level (thin line).

Finally Figure (B4) finds a negative association between exposure and employment outcomes, echoing the negative association between exposure and total energy use under the carbon tax regime. Yearly negative effects increase in magnitude albeit are only statistically significant at the five percent level during the last two years of the panel. Plants expecting relatively higher carbon costs in the future shed some of their polluting activities to cut down future costs, thereby also shedding jobs associated with such activities.

The statistically significant effect in 2013 may reflect anticipatory behavior. In end 2012 the French government organized its first multi-stakeholder Environment Conference with green taxation as one of its major themes for discussion. To help meet international climate agreements and national carbon mitigation objectives it advocated both for the implementation of European carbon pricing and its own national excise duty on carbon. As a result, the multi-stakeholder Environment Taxation Committee (*Comité pour la fiscalité écologique*) was created in 2013 and tasked with assessing and formulating implementable carbon pricing policy measures in France for the following year. In parallel in 2011 the EU Commission proposed to revise the Directive 2003/96/EC to include a carbon tax of €20 per tCO_2 on energy use outside the European carbon market (EU-ETS), to be introduced in 2013 (Cours des Comptes, 2019; Citepa, 2011). In anticipation to higher carbon costs, industry managers internalized expected future carbon prices in their production and investment decisions.

Figure 5: Event study DiD effect of exposure to carbon pricing (%) on total energy use (log)



Note: see Note under Figure (4)

Table (1) presents average effects of exposure and expected exposure to increasingly stringent carbon pricing on the various outcomes of interest. The coefficients on the electricity use share, the electricity to fossil fuel use ratio and the electricity use level are all positive although not statistically significant for the latter outcome. A 10 percentage point (pp) increase in expected exposure increases the electricity use share by around 1.9 pp and the electricity to fossil fuel use ratio by around 4.86% in the post-reform period relative to pre-reform under model specification (6). On the other hand, the effects on total energy use, the fossil fuel use level and employment are all negative. A 10 pp increase in exposure lowers relative total energy use by around 4.39% at the one percent level. Exposure is negatively associated with fossil fuel use, albeit statistically significance is weak and not constant across model specifications. Under the last specification, a 10 pp increase in exposure lowers fossil fuel use by around 3.7% at the ten percent level. The negative effect on job outcomes is no longer statistically significant from specification (4).

Table 1: Average DiD effects of exposure to carbon pricing (%)

Models	(1)	(2)	(3)	(4)	(5)	(6)
Outcome: Electricity use share (%)						
Exposure to carbon pricing (%) × Post	.11496***	.19150***	.19299***	.19307***	.19405***	.19403***
	(.01244)	(.03573)	(.03680)	(.03685)	(.03730)	(.03737)
	.875	.880	.881	.881	.881	.881
Outcome: Total energy use level (log)						
Exposure to carbon pricing (%) × Post	-.00198***	-.00434**	-.00406***	-	-.00450***	-.00439***
	(.00040)	(.00108)	(.00109)	-	(.00107)	(.00197)
	.939	.942	.942	-	.942	.943
Outcome: Electricity use level (log)						
Exposure to carbon pricing (%) × Post	.00047	.00044	.00063	.00099	.00043	.00053
	(.00046)	(.00108)	(.00108)	(.00108)	(.00112)	(.00112)
	.949	.953	.953	.953	.953	.954
Outcome: Fossil fuel use level (log)						
Exposure to carbon pricing (%) × Post	-.00513***	-.00312	-.00348*	-.00311	-.00374*	-.00370*
	(.00056)	(.00215)	(.00211)	(.00215)	(.00213)	(.00213)
	.906	.910	.910	.911	.911	.911
Outcome: Electricity to fossil fuel use ratio (log)						
Exposure to carbon pricing (%) × Post	.00558***	.00430*	.00478**	.00477**	.00482**	.00486**
	(.00062)	(.00220)	(.00218)	(.00225)	(.00227)	(.00228)
	.885	.889	.889	.889	.889	.889
Outcome: Employment level (log)						
Exposure to carbon pricing (%) × Post	-.00178***	-.00168**	-.00130*	-.00111	-	-.00115
	(.00030)	(.00070)	(.00072)	(.00072)	-	(.00072)
	.962	.966	.967	.967	-	.967
Plant dummies	Y	Y	Y	Y	Y	Y
Industry × Post		Y	Y	Y	Y	Y
Region × Post			Y	Y	Y	Y
Total energy use in 2005 × Post				Y	Y	Y
Employment in 2005 × Post					Y	Y
Firm-level total sales in 2005 × Post						Y

Note:
Both total energy use and employment as an independent variable is omitted from the regression equation when included as the outcome. Exposure and expected exposure to carbon pricing is proxied by the estimated growth in total energy costs, or Equation (1). The electricity use share refers to Equation (4) in Footnote (4). Post is a dummy equalling one for the post-reform period (2014 - 2019). Industry is defined at the four-digit NACE Rev.2 industry code level. Standard errors are provided in parenthesis and are clustered at the plant level. Adjusted R-squares are provided below the standard errors. Statistical significance is marked with *(0.1 > p-value > 0.05), **(0.05 > p-value > 0.01), ***(p-value < 0.01).

6.1 Robustness checks

Electricity and fossil fuel consumption represent 97% of total energy use in the Eacei database. In addition to electricity power, other fuels that are not subject to the national carbon excise duty include vapor, black liquor, wood, special renewable fuels and special non-renewable fuels. Figure (C1) illustrates the event study estimates where the outcome of interest is the share of fuels not subject to carbon taxation of total energy use so as to ascertain that results are not driven by the omission of the additional fuels. Yearly estimates are akin to those found in Figure (4).

Moreover, the underlying assumption when using the main continuous dependent variable, $\text{Exposure}_{i,<2014}$, is that the relatively more exposed plants react differently from the relatively less exposed plants to the introduction of the carbon tax regime. To verify this assumption further, the main dependent variable is replaced with $\text{DExposure}_{i,<2014}$, or Equation (2). Table (C1) presents the average effects when using the dummy as the main dependent variable. On average, the most exposed plants experience around a 3.8 pp increase in the electricity use share relative to the least exposed plants, along with a 10% drop in total energy use. Nevertheless all other average effects are not statistically significant. Figure (C2) show the associated event study result for the electricity use share. The graphical conclusions broadly do not change although post-reform effects are less linear with some differential pre-trends in 2010 and in 2011.

Thirdly, results are again re-estimated based on a sample where plants exclusively consume a non-null amount of both electricity and fossil fuels across all years of the panel. Doing so may ensure that plants have similar capital equipment to exploit both types of fuels each year. The final balanced sample includes 719 plants per year. Table (C2) presents the average effects based on the alternate sample. With the exception of fossil fuel use and the electricity to fossil fuel use ratio, average results are lower in magnitude relative to those found in Table (1), although conclusions are broadly the same. The downward effect of exposure on fossil fuel use is statistically significant at the five percent level under the last model specification: a 10 pp increase in exposure lowers fossil fuel consumption by 4.5 percent. Figure (C3) shows the event study effects for the electricity use share. While post-reform trends are broadly akin to Figure (4), estimates are only statistically significant at the five percent level from 2016 onward.

7 Discussion

The carbon tax is not a stand-alone environmental tax policy, but integrated within broader French climate and energy policy reform. In parallel to the Paris Agreement, the 2015 Energy Transition for Green Growth Act (LTCEV) not only sets the long-term trajectory of the tax, but also includes carbon mitigation and sector-specific road-maps or "carbon budgets" (SNBC, *Stratégie Nationale Bas-Carbone*)[6]. It is also noteworthy that with Article 173 of the LTECV France became the first country to require listed companies, banks and credit providers and institutional investors to report - on a

[6]The 2015 SNBC was revised in 2019 (SNBC 2) and included more ambitious climate goals for industry. In line with SNBC 2 objectives, the mining and metallurgy, the chemical and cement sectors target a 31%, 26% and 25% reduction in emissions by 2030, respectively (National Industry Council, 2021a; National Industry Council, 2021b; National Industry Council, 2021c).

comply or explain basis - on their exposure to financial risks related to climate change (UNEPFI, 2016)[7]. In this context, it is plausible that businesses are more generally expecting increasingly stringent carbon pricing in the future more broadly. Nevertheless, the introduction of an explicit carbon tax and its longer-term trajectory serves as an important credible signal that carbon-intensive production will increasingly become relatively less profitable

As noted in Section (5.1), a threat to the identification strategy is that results capture shocks and trends that are correlated with the effects of carbon pricing that are unaccounted for in the regression controls. Auctioning became the default method for allocating emissions permits in the European carbon market at the start of Phase 3 in 2013. While the analysis excludes the much larger EU-ETS participants, it cannot exclude the possibility of spillover effects of the change in allocation rules onto non-participants. Secondly, from January 2013 most businesses could benefit from a tax credit (CICE, *Crédit d'impôt pour la compétitivité et l'emploi*) to encourage investment and hiring. The CICE was partly financed by carbon tax revenues until 2017 (Ministère de la Transition Ecologique, 2017). Nevertheless, France Stratégie (2020) uncovers little evidence of a significant effect of the CICE on either employment nor investment in industry. Thirdly, the government reformed the taxation of electricity in 2016. The reform led to a slight increase in the national excise duty on electricity use, as well as introduced new preferential tax treatment policies, to the benefit of large electricity consumers, to replace previously applied measures. Figure (A2) indicates that the average cost of electricity consumption does not markedly differ between low and highly exposed plants across all years of the panel, undercutting the hypothesis that results are capturing the effects of the 2016 reform.

8 Concluding remarks

This paper empirically estimates the effects of exposure and expected exposure to increasingly stringent carbon pricing policy on plant-level consumption patterns and employment outcomes in French manufacturing from 2005 to 2019. Findings reveal that expectations of higher exposure to carbon pricing is positively associated with a higher share of electricity use likely driven by lower total energy use levels among the most exposed plants under a carbon tax regime. Evidence additionally suggest that expected exposure is not associated with a change in electricity use consumption, and instead is weakly associated with a drop in fossil fuel consumption. On average, a 10 percentage point (pp) increase in exposure increases the electricity share by 1.9 pp, lowers total energy use by around 4.39% and increases the electricity to fossil fuel ratio by 4.86% at statistically significant levels. Finally, evidence also indicates that expected exposure to carbon pricing is also weakly associated with lower employment outcomes. Importantly, graphical results suggest a lack of pre-trends from 2005 to 2012, with plausible anticipation effects a year prior the reform.

[7] Using a DiD specification, Mésonnier and Nguyen (2021) investigate the effect of this new requirement implemented in 2016 on the funding of carbon-intensive industries. They uncover a sharp relative decrease of around 39% in holdings of fossil fuel securities after December 2015 among institutional investors in France, with little evidence of pre-trends from 2013 through 2015.

Risk-averse and forward-looking plants anticipate and prepare for expected higher carbon prices by making production and investment decisions to lower immediate and future carbon costs. Simply put, findings reveal that plants most exposed to higher future carbon costs in France proactively shed some of their carbon-intensive activities, thereby lowering their fossil fuel use levels as well as lowering job outcomes associated with such activities, and relative to plants that are less exposed. As a result, reliance on low-carbon electricity power for production purposes increases under the carbon tax regime. While this paper does not address whether fossil fuel use decrease in aggregate across all plants, it does underline the fact that a carbon tax encourages a reduction in fossil fuels, i.e., a narrowing of its tax base, among those that are most exposed to it. More broadly, findings highlight the importance of a credible, strong and long-term carbon price signal to attain national environmental objectives and motivate a change in polluting behavior.

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A Descriptive statistics

Table A1: Descriptive statistics in 2005

	Mean	Median	Std.Dev.	Min	Max
Electricity use share (%)	57	56	23	6	100
Estimated growth in energy costs (%)	21	20	14	0	77
Electricity over fossil fuel use ratio	10	1	63	0	940
Total energy use (‘1 000 toe)	2	1	3	0	49
Total energy costs (‘1 000 €)	825	459	1 240	24	14 601
Plant employment (#)	337	230	350	23	4 200
Firm-level total sales (‘1 000 000 €)	164	58	353	0	3 203
Industry sector composition (Freq., %)					
Chemicals and chemical products (20)	16				
Other non-metallic mineral products (23)	12				
Fabricated metal products (25)	12				
Electrical equipment (27)	7				
Basic metals (24)	7				
Rubber and plastic products (22)	7				
All other manufacturing	39				

Note: Values are rounded to the nearest integer. The electricity use share refers to the following equation:

$$\text{Electricity use share}_{i,2005} \equiv \left[\frac{\text{Electricity use}}{(\text{Electricity use} + \text{Fossil fuel use})}\right]_{i,2005} \times 100$$

and the estimated growth in energy costs refers to Equation (1). Toe is an acronym for tons of oil equivalent. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. The 2-digit NACE Rev.2 industry code are provided in parenthesis. The balanced panel, after omitting EU-ETS participants, includes 834 plants per year.

Table A2: Descriptive statistics by exposure level in 2005

	Low exposure					High exposure				
	Mean	Median	Std.Dev.	Min	Max	Mean	Median	Std.Dev.	Min	Max
Electricity use share (%)	76	75	14	46	100	37	39	13	6	77
Estimated growth in energy costs (%)	10	11	6	0	20	33	29	11	20	77
Electricity over fossil fuel use ratio	20	3	90	0	940	1	1	3	0	54
Total energy use ('1 000 toe)	1	1	3	0	31	2	1	4	0	49
Total energy costs ('1 000 €)	724	388	1 178	25	14 601	926	553	1 292	24	12 572
Plant employment (#)	387	252	418	26	4, 200	287	198	256	23	1 551
Firm-level total sales ('1 000 000 €)	172	58	341	0	3 203	157	57	365	0	3 203

Industry sector composition (Freq., %)

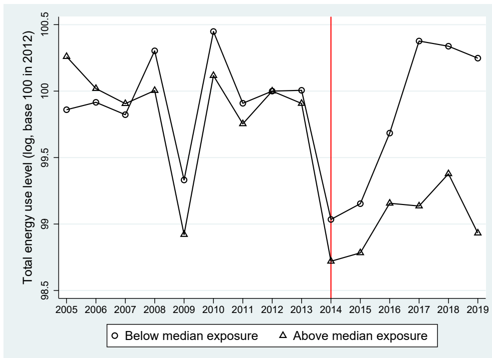
Low exposure		High exposure	
Fabricated metal products	12	Chemicals and chemical products	20
Rubber and plastic products	11	Other non-metallic mineral products	14
Chemicals and chemical products	11	Fabricated metal products	11
Other non-metallic mineral products	10	Basic metals	11
Electrical equipment	9	Basic pharmaceutical products	8
Paper and paper products	6	Paper and paper products	6
Other manufacturing	41	Other manufacturing	30

Note: Values are rounded to the nearest integer. Low and high exposure to carbon pricing refer to plants with an average pre-reform estimated growth in total energy costs (Equation (1)) below and above its median value in the panel, respectively. The electricity use share refers to the following equation:

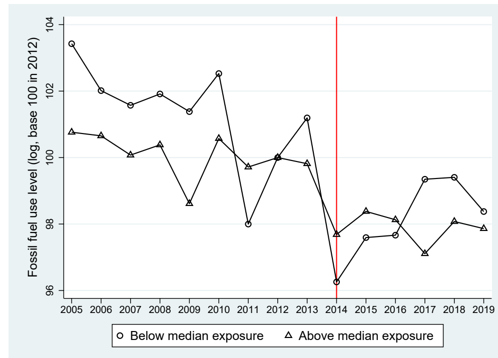
$$\text{Electricity use share}_{i,2005} \equiv \left[\frac{\text{Electricity use}}{(\text{Electricity use} + \text{Fossil fuel use})}\right]_{i,2005} \times 100$$

. Toe is an acronym for tons of oil equivalent. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. The balanced panel, after omitting EU-ETS participants, includes 834 plants per year.

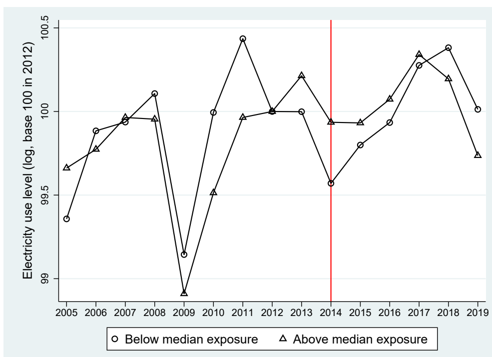
Figure A1: Parallel trends



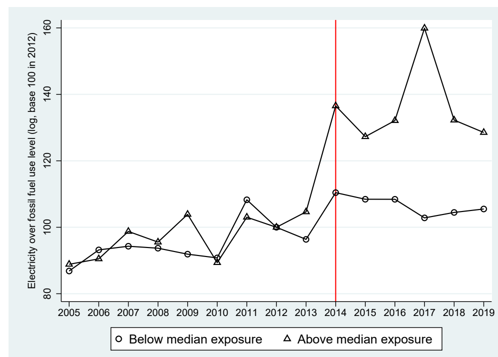
(a) Total energy use (log)



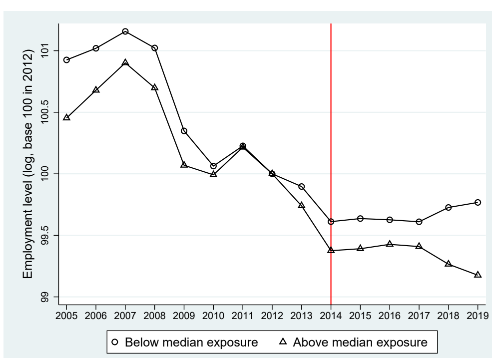
(b) Fossil fuel use (log)



(c) Electricity use (log)



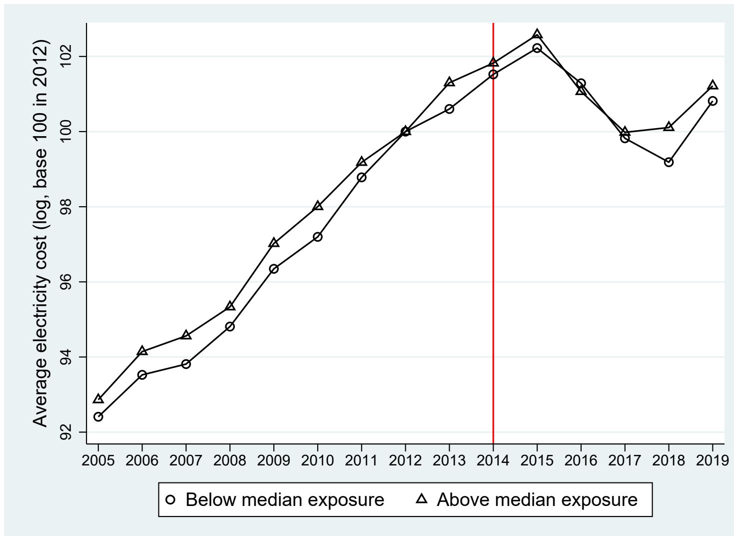
(d) Electricity over fossil fuel use ratio



(e) Employment (log)

Note: Exposure level is determined at its median value, as detailed in Equation (2). Trends are indexed to year 2012.

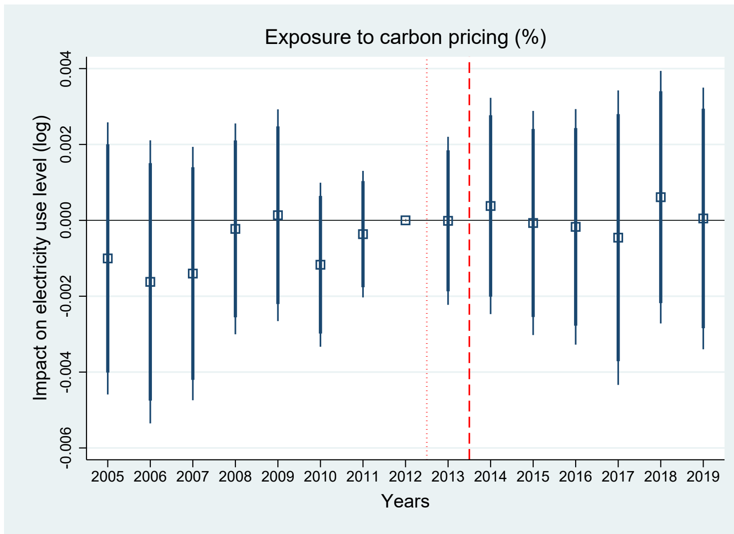
Figure A2: Parallel trends - average electricity cost



Note: Exposure level is determined at its median value, as detailed in Equation (2). Trends are indexed to year 2012.

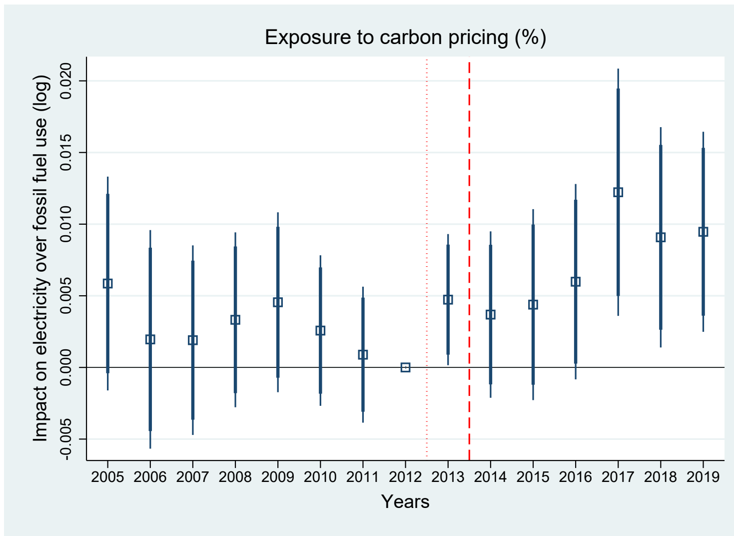
B Results

Figure B1: Event study DiD effect of exposure to carbon pricing (%) on electricity use levels (log)



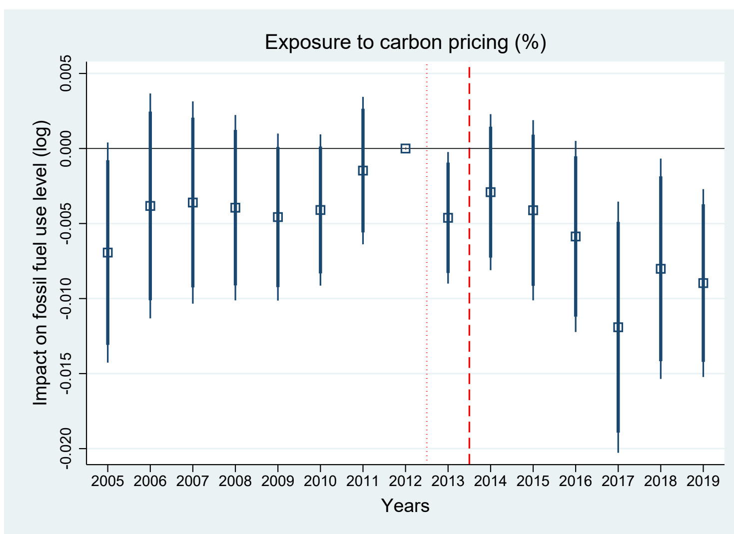
Note: see Note under Figure (4)

Figure B2: Event study DiD effect of exposure to carbon pricing (%) on the electricity to fossil fuel use ratio (log)



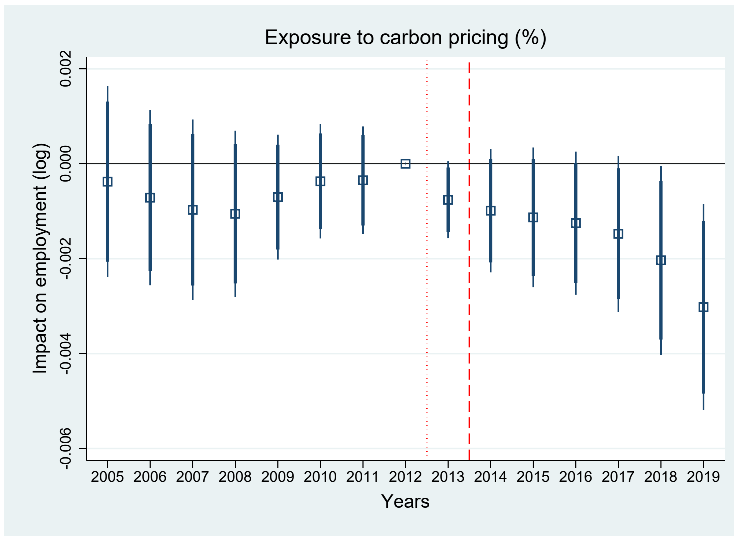
Note: see Note under Figure (4)

Figure B3: Event study DiD effect of exposure to carbon pricing (%) on fossil fuel levels (log)



Note: see Note under Figure (4)

Figure B4: Event study DiD effect of exposure to carbon pricing (%) on employment levels (log)



Note: see Note under Figure (4)

C Robustness checks

Table C1: Average DiD effect of exposure to carbon pricing (dummy)

Models	(1)	(2)	(3)	(4)	(5)	(6)
Outcome: Electricity use share (%)						
Exposure to carbon pricing (dummy) × Post	3.78804***	3.87851***	3.79709***	3.78337***	3.77359***	3.77843***
	(.42104)	(.91809)	(.93771)	(.93730)	(.94046)	(.94641)
	.875	.879	.880	.880	.880	.880
Outcome: Total energy use level (log)						
Exposure to carbon pricing (dummy) × Post	-.06075***	-.09385***	-.09479***	-	-.10523***	-.10051***
	(.01446)	(.02638)	(.02618)	-	(.02556)	(.02553)
	.938	.942	.942	-	.942	.942
Outcome: Electricity use level (log)						
Exposure to carbon pricing (dummy) × Post	.01570	-.01054	-.01242	-.00592	-.01888	-.01400
	(.01508)	(.02504)	(.02528)	(.02512)	(.02549)	(.02539)
	.949	.953	.953	.953	.953	.954
Outcome: Fossil fuel use level (log)						
Exposure to carbon pricing (dummy) × Post	-.14948***	-.06455	-.07283	-.06624	-.07956	-.07711
	(.01976)	(.05434)	(.05343)	(.05394)	(.05309)	(.05379)
	.906	.910	.910	.910	.911	.911
Outcome: Electricity to fossil fuel use ratio (log)						
Exposure to carbon pricing (dummy) × Post	.16497***	.06589	.06951	.06889	.06887	.07102
	(.02052)	(.05262)	(.05226)	(.05323)	(.05334)	(.05394)
	.884	.888	.889	.889	.889	.889
Outcome: Employment level (log)						
Exposure to carbon pricing (dummy) × Post	-.05094***	-.04141**	-.03579*	-.03231*	-	-.03054
	(.01238)	(.01933)	(.01962)	(.01954)	-	(.01929)
	.962	.966	.967	.967	-	.967
Plant dummies	Y	Y	Y	Y	Y	Y
Industry × Post		Y	Y	Y	Y	Y
Region × Post			Y	Y	Y	Y
Total energy use in 2005 × Post				Y	Y	Y
Employment in 2005 × Post					Y	Y
Firm-level total sales in 2005 × Post						Y

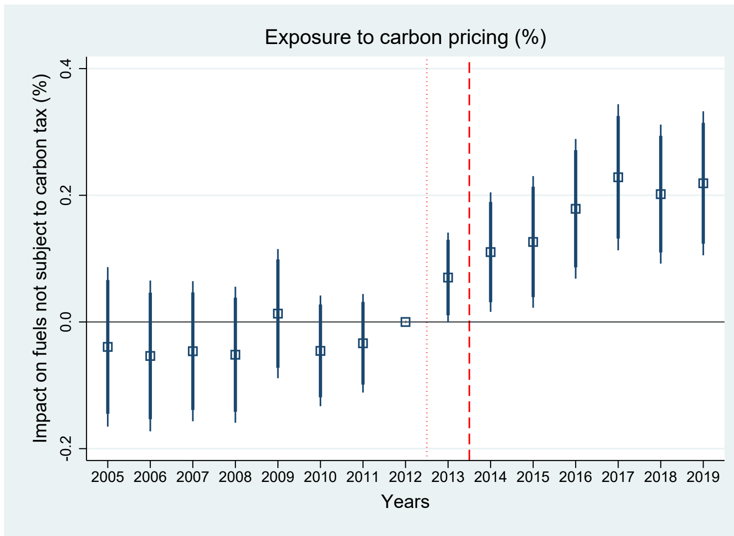
Note:
Borth total energy use and employment as an independent variable is omitted from the regression equation when included as the outcome. Th dummy for exposure and expected exposure level to carbon pricing is estimated from Equation (2). Electricity use refers to the Equation (4). Post is a dummy equalling one for the post-reform period (2014 - 2019). Industry is defined at the four-digit NACE Rev.2 industry code level. Standard errors are provided in parenthesis and are clustered at the plant level. Adjusted R-squares are provided below the standard errors. Statistical significance is marked with *(0.1 > p-value > 0.05), **(0.05 > p-value > 0.01), ***(p-value < 0.01).

Table C2: Average DiD effect of exposure to carbon pricing (%), based on sample consuming a non-null amount of electricity and fossil fuels

Models	(1)	(2)	(3)	(4)	(5)	(6)
Outcome: Electricity use share (%)						
Exposure to carbon pricing (%) × Post	.10031***	.12892***	.12927***	.13050***	.13322***	.13298***
	(.01201)	(.03720)	(.03758)	(.03799)	(.03871)	(.03873)
	.898	.802	.903	.903	.903	.903
Outcome: Total energy use level (log)						
Exposure to carbon pricing (%) × Post	-.00188***	-.00324**	-.00318***	-	-.00380***	-.00373***
	(.00040)	(.00114)	(.00114)	-	(.00111)	(.00111)
	.949	.952	.953	-	.953	.953
Outcome: Electricity use level (log)						
Exposure to carbon pricing (%) × Post	.00039	.00140	.00136	.00170	.00106	.00111
	(.00048)	(.00119)	(.00119)	(.00119)	(.00125)	(.00125)
	.957	.961	.961	.961	.962	.962
Outcome: Fossil fuel use level (log)						
Exposure to carbon pricing (%) × Post	-.00490***	-.00356	-.00405*	-.00370*	-.00455**	-.00450**
	(.00056)	(.00217)	(.00212)	(.00217)	(.00212)	(.00212)
	.907	.911	.912	.912	.912	.912
Outcome: Electricity to fossil fuel use ratio (log)						
Exposure to carbon pricing (%) × Post	.00528***	.00497**	.00541**	.00541**	.00561**	.00561**
	(.00063)	(.00228)	(.00226)	(.00233)	(.00236)	(.00236)
	.878	.883	.884	.884	.884	.884
Outcome: Employment level (log)						
Exposure to carbon pricing (%) × Post	-.00182***	-.00139*	-.00121	-.00104	-	-.00115
	(.00031)	(.00075)	(.00077)	(.00078)	-	(.00077)
	.962	.967	.967	.967	-	.968
Plant dummies	Y	Y	Y	Y	Y	Y
Industry × Post		Y	Y	Y	Y	Y
Region × Post			Y	Y	Y	Y
Total energy use in 2005 × Post				Y	Y	Y
Employment in 2005 × Post					Y	Y
Firm-level total sales in 2005 × Post						Y

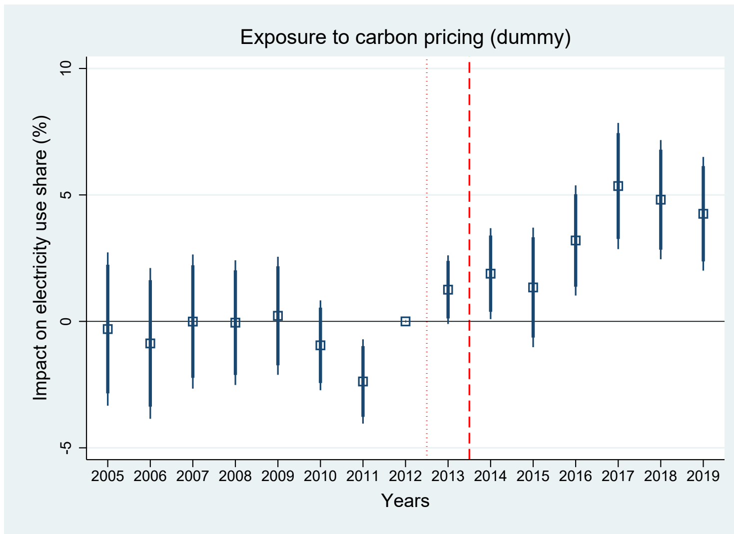
Note:
Results are estimated based on a sample of plants that consume a non-null amount of both electricity and fossil fuels across all years of the panel. The panel includes 714 plants per year. Both total energy use and employment as an independent variable is omitted from the regression equation when included as the outcome. Exposure and expected exposure to carbon pricing is proxied by the estimated growth in total energy costs, or Equation (1). Electricity use refers to the Equation (4). Post is a dummy equalling one for the post-reform period (2014 - 2019). Industry is defined at the four-digit NACE Rev.2 industry code level. Standard errors are provided in parenthesis and are clustered at the plant level. Adjusted R-squares are provided below the standard errors. Statistical significance is marked with *(0.1 > p-value > 0.05), **(0.05 > p-value > 0.01), ***(p-value < 0.01).

Figure C1: Event study DiD effect of exposure to carbon pricing (%) on the share of fuels not subject to the carbon excise duty (%)



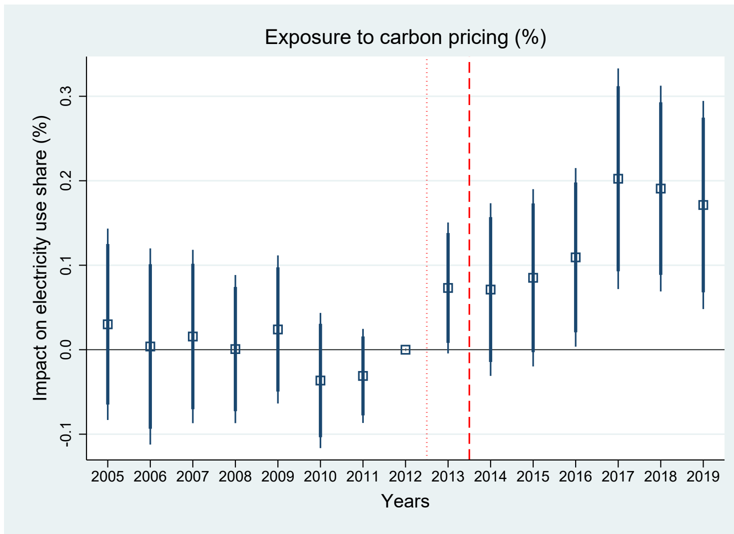
Note: Exposure to carbon pricing is proxied by the estimated growth in total energy costs, or Equation (1). Figure (4) shows results from Equation (5). The outcome variable is the share of fuels not subject to the carbon excise duty out of total energy use (%). Such fuels include electricity, vapor, black liquor, wood, special renewable fuels and special non-renewable fuels. The final balanced panel omits participants in the European carbon market, and includes 834 plants per year. Standard errors are clustered at the plant-level. Confidence intervals are set at the 10% level (thick line) and at the 5% level (thin line).

Figure C2: Event study DiD effect of exposure to carbon pricing (dummy) on the electricity use share (%)



Note: The dummy variable for exposure to carbon pricing is calculated in Equation (2). Figure (4) shows results from Equation (5). The electricity use share refers to Equation (4) in Footnote (4). The final balanced panel omits participants in the European carbon market, and includes 834 plants per year. Standard errors are clustered at the plant-level. Confidence intervals are set at the 10% level (thick line) and at the 5% level (thin line).

Figure C3: Event study DiD effect of higher exposure to carbon pricing (%) on the electricity use share (%), based on sample consuming a non-null amount of electricity and fossil fuels



Note: Exposure to carbon pricing is proxied by the estimated growth in total energy costs, or Equation (1). Figure (4) shows results from Equation (5). The electricity use share refers to Equation (4) in Footnote (4). Results are estimated based on a sample of plants that consume a non-null amount of both electricity and fossil fuels across all years of the panel. The final balanced panel omits participants in the European carbon market, and includes 719 plants per year. Standard errors are clustered at the plant-level. Confidence intervals are set at the 10% level (thick line) and at the 5% level (thin line).

D Emission factors

Table D1: Emission factors

	Emission Factor (tCO2e)	Unit
Natural gas	0.205	MWh
Other gases	0.599	MWh
Coal	2.77	tonne
Lignite	1.87	tonne
Coal coke	3.27	tonne
Petroleum coke	3.5	tonne
Butane-propane	3.455	tonne
Heavy fuel oil	3.64	tonne
Domestic fuel oil	0.00325	litre

Note: Units refer to the metric units provided in the Eacei database by fuel use. Emission factors come from Ademe (2021), and are applied to each fuel according to their metric unit across all years. The application of an emission factor to each fuel yields the amount of tons of carbon emissions (tCO_2) it pollutes. The emission factor for 'other gases' refer to the unweighted average of emission factors for steel mill gas, coke oven gas and blast furnace gas. The emission factor for 'coal' refers to the unweighted average of emission factors for anthracite, coking coal and steam coal. The emission factor for 'butane-propane' refers to the unweighted average of emission factors for butane and propane.