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Carbon tax reform and French industry response
Insights from panel data, 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 constructs a proxy for exposure and expected exposure to increasingly higher carbon pricing, as the rate was expected to reach €100 per tCO_2 by 2030. A 10 percentage point (pp) increase in exposure is significantly associated with a 2.03 pp increase in the share of electricity over fossil fuel use. This increase is more likely driven by a decrease in total energy use, and particularly in fossil fuel use. Additional results uncover evidence of input shifting across fossil fuel inputs to the benefit of natural gas, as well as in improvements in energy efficiency. Findings does not suggest that exposure is associated with job losses on average.

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., 2024). 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. The gradual planned transition to higher carbon tax rate values in France was designed as a clear and reliable signal for economic agents regarding medium to long-term energy national transition ambitions. Its aim was to exploit low-cost abatement opportunities, avoid economic disruption, and stimulate corporate investment in carbon-efficient technologies (Quinet, 2009).

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. Accordingly, corporate behavior and investment choices are driven by profitability expectations, and rational investors consider the long-term evolution of carbon values, not just their initial levels (Quinet, 2009). 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. For firms, 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. 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 carbon tax. On the other hand, fossil fuel use is subject to the tax. The main exposure variable represents the percentage increase in total energy costs attributable to the estimated carbon costs brought about by the French carbon tax reform and its long-term trajectory. Hence plants that are more reliant on fossil fuels relative to electricity estimate a larger increase in their future energy bill due to the carbon tax.

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 significantly associated with a 2.03 pp increase in the share of electricity over fossil fuel use, where electricity is not subject to the carbon tax in France. This increase is more likely driven by a decrease in total energy use, and particularly in fossil fuel use, as opposed to an increase in electricity use. Findings also suggest evidence of possible input shifts across fossil fuels to the benefit of less carbon-intensive natural gas use, contributing jointly to cuts in the carbon intensity of fossil fuel use, as well in a drop in the amount of carbon emissions emitted in manufacturing. Furthermore, and despite cuts in total energy use, evidence does not suggest that exposure is associated with job losses on average. This finding mitigates concerns about a decline in corporate profitability due to the carbon tax. Instead, results suggest improvements in terms of energy efficiency. Overall, findings reveal that plants most exposed to higher future carbon costs in France proactively shed some of their carbon-intensive activities. 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, exploiting the peculiarities of the French energy mix and tax system, the principal contribution of this paper is an empirical investigation of 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, and based on micro panel data.

The next section briefly overviews the related empirical literature. Section (2) describes the institutional background in France and Section (3) presents the data sources, the key variable used in the analysis and summary statistics. Section (4) describes the empirical strategy and Section (5) details the empirical findings and robustness checks. Section (6) provides a discussion of results. The last section concludes.

1.1 Related empirical literature

First, this paper contributes to the empirical literature on the effects of carbon pricing on environmental and economic activities. Market-based, or price-based, policies encourage a change in behavior through market signals rather than through explicit directives regarding pollution control levels or methods (Portney and Stavins, 1998). Note that carbon pricing policies encompass both carbon taxes and cap-and-trade systems. In a review of the relatively scarce ex-post literature, Green (2021) not only concludes that aggregate reductions on emissions are limited, but also notes that drivers of emission reductions often reflect incremental solutions (fuel switching, enhanced efficiency) as opposed to broader decarbonization. Using an alternate literature review methodology, Döbbeling-Hildebrandt et al. (2024) find consistent evidence that carbon pricing tools cause emission reductions ranging between 4% and 15%, despite low levels of prices. In a different review, Dechezleprêtre and Sato (2017) conclude more broadly that the cost burden of environmental policies on various indicators of competitiveness are relatively small, particularly compared with other determinants of trade and investment location choices.

Secondly, this paper provides insights into how carbon pricing policy design influence corporate behavior, particularly with respect to anticipations of increasing carbon stringency. Campiglio, Lamperti and Terranova (2024) note that stated policy intentions can serve as a key anchor to drive expectations. More generally, policy credibility is of paramount importance to motivate low-carbon innovation and long-term investments and achieve climate targets set out in the Paris Agreement (Rogge and Dütschke, 2018). In contrast, policy volatility and uncertainty can lead to skepticism about policy commitments, hindering the energy transition (Campiglio, Lamperti and Terranova, 2024). Uncertainty around present and future climate policy can lead to a steady growth of the fossil fuel industry (Lin and Zhao, 2023). Accordingly, Thibault and Lefevre (2024) estimate that failing to get expectations right can increase cumulative carbon emissions by 11.1% compared to models where economic agents have perfect policy foresight. Hensel, Mangiante and Moretti (2024) uncover evidence that increases in carbon pricing is associated with strong increases in firm-level inflation expectations in France, both in terms of anticipated and realized own-price growth, indicating a close alignment between heightened price expectations and actual increases. They also note that French firms initially underestimate the impact of carbon price increases on their own prices and overestimate them in the medium to long term. Bauer et al., 2018 further argue that strong and timely signals from policymakers that fosters expectations of increasingly stringent future carbon taxes can help overcome any green paradox behavior[1]. Corporate behavior and investment choices are driven by profitability expectations, and rational investors consider the long-term evolution of carbon values, not just their initial levels (Quinet, 2009).

Thirdly, this paper contributes to the literature on the impacts of carbon taxation in the manufacturing sector. A carbon tax is a price set per ton of carbon emissions. Employing both an IV and DiD design, Martin, de Preux and Wagner (2014) conclude that the tax is associated with reductions in energy intensity among larger and more energy-intensive plants, driven by reductions in carbon-intensive electricity use and translating into cuts in carbon emissions in UK manufacturing. Nevertheless, they do not find significant impacts on employment, revenue, total factor productivity (TFP), nor on plant exiting. Ahmadi, Yamazaki and Kabore (2022) similarly estimate that the carbon tax in British Columbia (BC) cut manufacturing emissions by 4%, albeit while increasing plant output. They posit that as carbon tax revenues in BC are recycled into cuts in corporate income tax (CIT) rates, plants are better able to invest in energy-saving technologies and become more energy efficient. In Swedish manufacturing, Martinsson et al. (2024) find an emission-to-carbon pricing elasticity of around

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[1] The "green paradox" reflects behavior whereby anticipated environmental regulations ultimately worsen climate change (Sinn, 2012). Accordingly, some empirical evidence indicates that when facing price-based regulations, agents anticipate the price increase by shifting the timing of purchase to avoid the additional cost, such as in the case of vehicles (Rittenhouse and Zaragoza-Watkins, 2018) and gasoline fuel (Coglianese et al., 2017). Note that Lemoine (2017) argues that storage markets are likely the primary driver of green paradox behavior to the extent that firms and investors no only do not stockpile investments, but also are more likely focused on long-term risks and returns rather than short-term savings.

2, with lower elasticities among firms with higher abatement costs and tighter financial constraints.

Finally, this paper specifically focuses on the effects of carbon taxation on French manufacturing outcomes. In France, manufacturing contributes to roughly 18% of total greenhouse gas emissions. Utilizing similar panel data as in this paper, both Marin and Vona (2021) and Dussaux (2020) investigates the effects of increases in energy prices in French manufacturing as a measure of increasing carbon pricing stringency. Taking a shift-share instrument approach, Marin and Vona (2021) uncover evidence of a trade-off between environmental and economic goals: an increase in energy prices is associated with cuts in energy use and in carbon emissions, along with a smaller negative impact on plant employment. They more generally estimate that a €56 per tCO_2 tax would cost 0.7% and 1.7% of French manufacturing jobs on average and among trade-exposed energy-intensive industries, respectively, for a 10% reduction in emissions. On the other hand, using a fixed-weight energy price instrument, Dussaux (2020) arrives at a conclusion similar to Marin and Vona (2021). Moreover, the author additionally concludes that variations in energy prices do not affect employment in aggregate across manufacturing due to worker reallocation between energy inefficient and efficient firms. In a simulation exercise, Dussaux (2020) estimates that a €44.6 per tCO_2 carbon tax reduces emissions while inducing a reallocation of 0.24% of the manufacturing workforce, albeit likely leaving total employment unaffected.

With respect to Marin and Vona (2021) and Dussaux (2020), the contributions in this paper are threefold. First, the inclusion of the electricity price in the overall treatment variable, as done in both papers, may introduce bias in the results since electricity power in France is not subject to the carbon tax. This paper addresses this potential bias by focusing on the actual tax base of the carbon tax: carbon emissions from fossil fuel consumption. By isolating the increase in total energy costs attributable solely to the carbon tax, this approach can provide a more reliable estimate of the impact of the carbon tax reform on manufacturing costs. Second, several studies have concluded that economic agents react differently to changes in carbon tax compared to fluctuations in energy prices (Brännlund, Lundgren and Marklund, 2014, Rivers and Schaufele, 2015; Andersson, 2019). Andersson (2019) observes that the carbon tax elasticity of demand is around three time larger than the price elasticity in Swedish transport. Carbon taxes carry a different set of information than random fluctuations in fuel prices (Mideksa, 2024), not only signaling a longer-term policy shift, but also stigmatizing the more carbon intensive products and activities (Brännlund, Lundgren and Marklund, 2014). Hence this paper's focus on costs borne by the carbon tax specifically helps mitigate bias that may arise from the differential response of firms to energy price changes driven by supply and demand factors relative to policy-based tax changes. Third, as the French carbon tax was introduced in 2014, this paper employs a dynamic DiD setup to account for both the temporal and the plant-level variation in exposure intensity to estimate the effect of the policy.

2 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[2], 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

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[2] 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

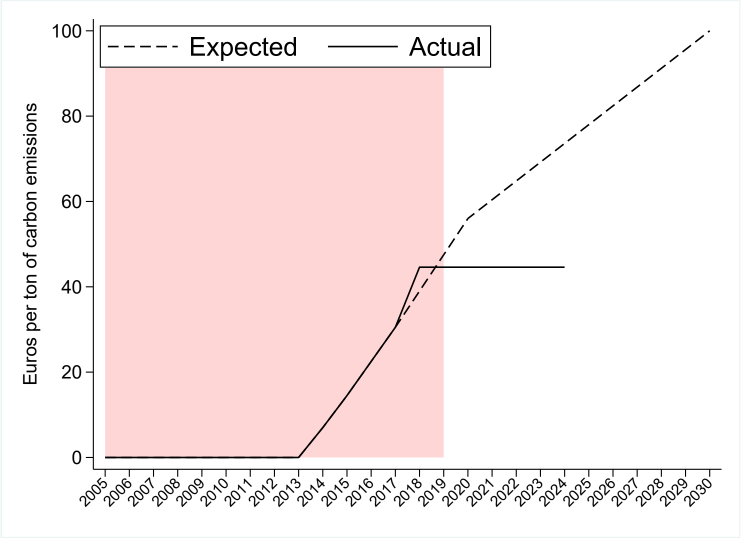

Figure 1 shows both the actual carbon tax rate applied to fossil fuels in France, as well as the expected rates as detailed in yearly Budget Acts and in the 2015 Energy Transition for Green Growth Act (LTECV). In 2019 following the yellow vests protests, the government froze the actual rate to its 2018 rate. Note that the section shaded in red represents all years in the panel (2005-2019). Sources: PLF, 2014; PLF, 2015 and PLF, 2018.

3 Data

3.1 Data sources and construction of panel

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 907 plants per year. It merges three different data-sets.

The Eacei (*Enquête sur les consommations d'énergie dans l'industrie*) database[3] 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

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

at least 20 employees. Stratification is based on activity classification and employment 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 across all fuels, as well only electricity relative to fossil fuels and vice-versa. On average, fossil fuels and electricity use represent around 96% 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 come from income statements and balance sheets. 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 EU-ETS is considered a cornerstone of EU climate change policy. It functions as a carbon market whereby the EU sets a cap on the amount of emissions regulated firms are allowed to emit. The resulting carbon price is determined by the market through the trading of emission allowances. 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 21% of plants are flagged as EU-ETS participants across all years. The final balanced panel omits EU-ETS participants as they are not liable to the carbon tax in France, amounting to 907 plants per year over fifteen years.

3.2 Construction of main treatment variable: exposure to carbon tax on fossil fuels

The Energy Transition for Green Growth Act sets a carbon tax rate of €100 per tCO_2 for 2030. A forward-thinking manager of plant i can estimate the full carbon cost she could expect to face in 2030, assuming no change in emitted emissions in year t.

$$\text{Estimated carbon costs}_{i,t} = \sum_{\text{Fossil fuels}} (\text{tCO}_2)_{i,t} \times \text{€}100 \text{ per tCO}_2$$

To calculate tons of carbon emissions (tCO_2), emissions factors (Ademe, 2021) 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. $\sum_{\text{Fossil fuels}}(tCO_2)_{i,t}$ represents the sum of tons of emissions for each plant i in year t.

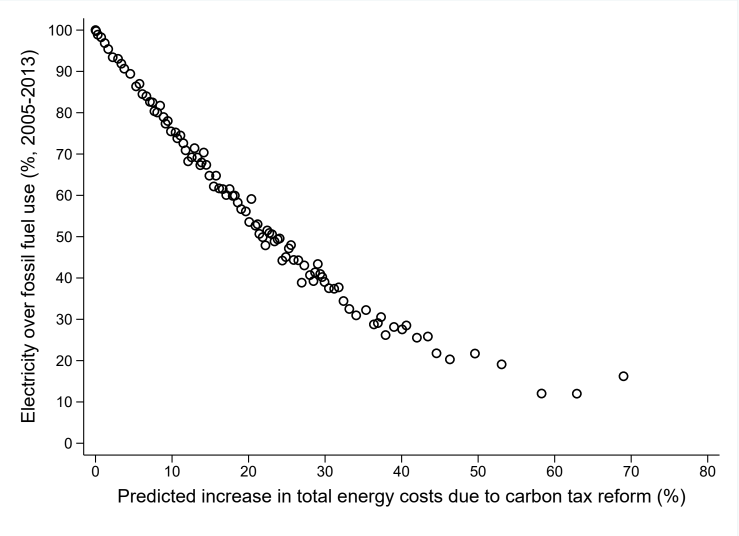
Equation (1) is the main exposure variable used in the study. It represents the average pre-reform (< 2014 : 2005-2013) percentage share of estimated or expected carbon costs over total energy costs for each plant i. Total energy costs include both costs from fossil fuel and electricity use.

$$\text{Exposure}_{i,<2014} \equiv \left[\frac{\text{Estimated carbon costs}}{\text{Total energy costs}}\%\right]_{i,<2014} \tag{1}$$

Equation (1) illustrates the importance of the carbon tax impact relative to overall energy expenditures for each plant. Simply put, it represents the percentage increase in total energy costs attributable to the estimated carbon costs brought about by the French carbon tax reform and its long-term trajectory. The underlying assumption is that plants are primarily concerned with their overall energy costs, inclusive of costs from electricity use, rather than specifically isolating fossil fuel costs. Accordingly, larger increases in Equation (1) should provoke stronger reactions from plants to change their polluting behavior because of their higher overall financial burden due to the carbon tax reform. On the other hand, plants that largely rely on electricity as inputs for production should have less incentives to change behavior since electricity represents a larger proportion of their energy costs. Note that as a robustness check, the analysis also provides results based on estimated carbon costs (the numerator in Equation 1) alone as an alternative measure of exposure.

Figure (2) illustrates how plants that consume relatively more electricity compared to fossil fuels do not estimate a considerable increase in total energy costs because of their lower exposure to the carbon tax reform On the other hand, plants that consume relatively larger amounts of fossil fuels can predict a larger financial burden due to the carbon tax in the future. The main takeaway from Figure (2) is that the estimated increase in total energy costs due to the carbon tax reform, as detailed in Equation (1), can serve as a proxy for exposure and expected exposure to the carbon pricing policy. The figure illustrates the almost straight-line negative relationship between exposure to the carbon tax and the relative amount of electricity consumed compared to fossil fuels. Overall, plants that consume electricity and fossil fuels in roughly equal amounts can estimate around a 23% increase in energy costs due to higher predicted carbon costs.

Figure 2: Correlation between electricity use over fossil fuel use (%) and the estimated increase in total energy costs due to the carbon tax reform (%)



Note: Figure (2) presents a binned scatter-plot. The x-axis refers to Equation (1). The y-axis refers to the pre-reform (< 2014 : 2005-2013) percentage share of electricity over fossil fuel use:

$$\text{Electricity over fossil fuel use}_{i,<2014} \equiv \left[\frac{\text{Electricity use}}{(\text{Electricity use} + \text{Fossil fuel use})}\%\right]_{i,<2014}$$

Electricity and fossil fuel use are expressed in tons of oil equivalents (toe).

3.3 Descriptive statistics

Table (1) presents descriptive statistics based on exposure level status as shown in Equation (2). Plants are identified as relatively more exposed when their estimated increase in energy costs due to carbon costs exceeds the median in the sample.

$$\text{DExposure}_{i,<2014} = \begin{cases} 1 \equiv \text{Relatively high, if Exposure}_{i,<2014} > \text{p50} \\ 0 \equiv \text{Relatively low, otherwise} \end{cases} \tag{2}$$

On average, the relatively more exposed plants estimate a 33% increase in their total energy bill due to the carbon tax, as opposed to 10% among the less exposed. As expected, the former consume more fossil fuels, both in relative terms and in levels. The relatively more exposed also consume more fossil fuels other than natural gas, translating into a higher carbon intensity of fossil fuels. Note that their relatively lower shares of fossil fuels other than natural gas reflects their larger amounts of fossil fuel consumption overall. The relatively more exposed consume more energy overall and incur higher energy bills, although employ less on average than the less exposed. They are also slightly smaller in terms of sales and assets. Finally, both groups of plants tend to face similar average electricity costs, although the more exposed tend to pay about €4 more on natural gas per MWh. The distribution of manufacturing sectors is rather homogeneous: chemicals, other non-metallic minerals, fabricated metals and paper are part of the 6 most frequently observed sectors across both groups of plants, representing 42% and 51% of plants among the least and most exposed, respectively.

Table 1: Summary statistics by exposure level (median) in 2005

	Exposure to French carbon tax			
	Relatively low exposure		Relatively high exposure	
	Mean	St. Dev.	Mean	St. Dev.
Estimated increase in energy costs due to carbon tax (%)	10	6	33	11
Electricity use over fossil fuel use (%)	74	17	36	14
Total electricity use (‘100 toe)	10	19	8	14
Total fossil fuel use (‘100 toe)	4	5	16	28
Electricity use over total energy use (%)	70	19	36	15
Fossil fuel use over total energy use (%)	26	17	63	15
Natural gas use over total fossil fuel use (%)	63	46	83	33
Fossil fuel use [excl. natural gas] (toe)	49	152	149	539
Fossil fuel use [excl. natural gas] over total fossil fuel use (%)	32	44	17	33
Total energy use (‘100, toe)	15	27	24	40
Total energy costs (‘1 000, €)	737	1 195	951	1 358
Employment (#)	391	415	300	290
Tons of carbon emissions from fossil fuel use (tC02)	986	1 686	4 339	7 720
Carbon intensity of fossil fuel use	3	0	3	1
Carbon intensity of total energy use	1	1	2	0
Average cost of electricity use (€ per MWh)	56	10	57	10
Average cost of natural gas (€ per MWh)	19	14	23	10
Firm-level sales (‘1 000 000)	194	358	182	473
Firm-level total net operating income (‘1 000 000)	13	42	13	50
Firm-level gross assets (‘1 000 000)	286	704	239	750
Export over total revenues (%)	35	29	36	28

Industry sector composition (Freq., %)

Relatively low exposure		Relatively high exposure	
Fabricated metals	12	Chemicals	21
Rubber and plastics	12	Other non-metallic minerals	13
Chemicals	11	Fabricated metals	11
Electrical equipment	10	Basic metals	10
Other non-metallic minerals	9	Basic pharmaceuticals	9
Paper	10	Paper	6
All other manufacturing sectors	40	All other manufacturing sectors	31

Note: Values are rounded to the nearest integer. Exposure status is defined in Equation (2). The electricity use over energy use ratio refers to the ratio of electricity use over the sum of electricity and fossil fuel use, with electricity and fossil fuel use representing around 96% of total energy use on average. 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. Energy use and plant-level variables come from EACEI. Firm-level variables come from tax returns. The balanced panel includes 907 plants per year that do not participate in the European cap-and-trade system.

Note that table (A1) additionally presents summary statistics based on exposure levels as shown in Equation (3) to further gauge potential heterogeneity in effects to the carbon tax.

$$\text{QExposure}_{i,<2014} = \begin{cases} \text{Q1, Least exposed, if Exposure}_{i,<2014} < \text{p25} \\ \text{Q2, Relatively less exposed, if} > \text{p25} \ \& < \text{p50} \\ \text{Q3, Relatively more exposed, if} > \text{p50} \ \& < \text{p75} \\ \text{Q4, Most exposed, if Exposure}_{i,<2014} > \text{p75} \end{cases} \tag{3}$$

4 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 tax at different levels of exposure contingent on energy use. Hence there is a lack of a clear control group of plants for identification in a standard Differences-in-Differences (DiD) strategy with binary treatment.

As a result, the empirical strategy exploits a continuous DiD specification, whereby the estimated increase in total energy costs due to the carbon tax - Equation (1) - proxies for exposure and expected future exposure to the reform. Note that the use of a percentage also accommodates for significant differences in energy use levels between plants. It is set at the pre-reform average because the exposure intensity after 2014 could become an outcome variable and change due to the carbon tax.

The event study specification is Equation (4). $y_{i,t}$ represents the outcome variable for plant i at time t, where t denotes years in the panel t = {2005,...,2019}. It includes a set of 15 year indicators $\mathbb{1}_{s=t}$ equalling one when the year observed, t, equals the specific indexed year s for which interaction is considered, and zero otherwise. The reference year (indicator) is set to 2012 for β_s. The main coefficient of interest, β_s, evaluates the evolution of the average effect of exposure to the carbon tax over the years.

$$\begin{aligned} y_{i,t} = \alpha_i + \sum_{\substack{s=2005 \\ s\neq 2012}}^{2019} \beta_s(\text{Exposure}_{i,<2014} \times \mathbb{1}_{s=t}) + \sum_k \sum_s \delta_{k,s}(industry_k \times \mathbb{1}_{s=t}) \\ + \sum_r \sum_s \gamma_{r,s}(region_r \times \mathbb{1}_{s=t}) + \sum_s \eta_s(\mathbf{X}_i^{2005} \times \mathbb{1}_{s=t}) + \varepsilon_{i,t} \end{aligned} \tag{4}$$

To help account for omitted variable bias, the event study results include plant dummies (α_i) to control for all time-constant characteristics that are specific to each firm. It also captures granular (4-digit NACE Rev. 2) sector-by-year shocks and trends, $\delta_{k,s}$, where k denotes each sector. They capture factors that affect all firms within a specific industry in a given year. Region-by-year shocks and trends that could explain differences in outcomes are captured through coefficient $\gamma_{r,s}$, where r denotes each French region. Coefficient η_s accounts for additional size effects: X_i^{2005} includes plant-level total energy costs, firm-level total gross assets, firm-level total sales and export share of revenues set at their 2005 levels to minimize correlation with the policy in the post-reform years. Coefficient $\varepsilon_{i,t}$ is the error term.

Equation (5) 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 ($t = 2014, ..., 2019$) and zero for pre-reform ($t = 2005, ..., 2013$). Both equations are constructed the same except for the terms on β_s and β.

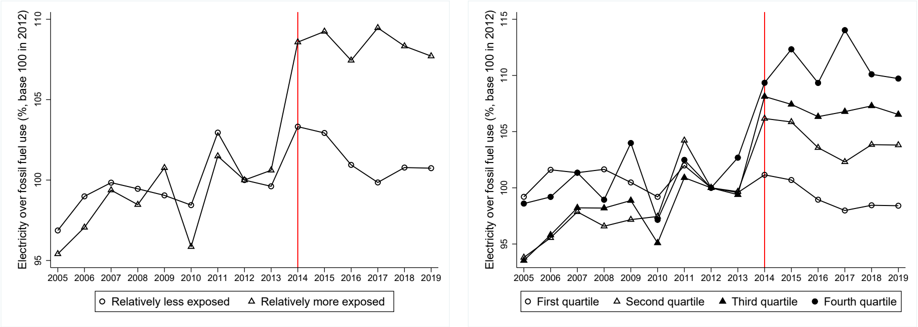
$$\begin{aligned} y_{i,t} = \alpha_i + \beta(\text{Exposure}_{i,<2014} \times Post_t) + \sum_k \sum_s \delta_{k,s}(industry_k \times \mathbb{1}_{s=t}) \\ + \sum_r \sum_s \gamma_{r,s}(region_r \times \mathbb{1}_{s=t}) + \sum_s \eta_s(\mathbf{X}_i^{2005} \times \mathbb{1}_{s=t}) + \varepsilon_{i,t} \end{aligned} \tag{5}$$

4.1 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 (4) 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 (3a) presents electricity use over fossil fuel use average trends, where the former is not subject to the carbon tax, of the relatively highly exposed plants compared to the less exposed, as defined in Equation (2).

Figure (3a) shows that the trajectory of both groups were broadly similar until 2014 - the year the carbon tax was introduced - when the ratio among the most exposed plants visibly increases relative to the least exposed by several percentage points. Figure (A1) illustrate the same indexed graphs for additional energy use and employment outcomes. Overall, pre-reform trajectories between the relatively less and more exposed look broadly similar. They generally indicate a visible difference in both total energy use and in the ratio of energy use over employment between both groups from 2014, whereby the more exposed do not experience a rise in energy use as their lesser exposed counterparts.

Figure 3: Parallel trends - electricity over fossil fuel use (%)



(a) by median

(b) by quartiles

Note: In Figure (3a), exposure levels are determined in Equation (2). In Figure (3b), exposure levels are determined in Equation (3). The fourth quartile refers to the most exposed plants, whereas the first quartile the least exposed. Electricity over fossil fuel use refers to the ratio of electricity use over the sum of electricity and fossil fuel use. Average trends are indexed to year 2012.

Figure (3b) presents the evolution of electricity over fossil fuel use by quartiles based on Equation (3). The ratio increases the most among plants in the fourth quartile, i.e. plants in the top 25% in terms of exposure to the carbon tax. The ratio increases the least among plants in the first quartile, i.e. plants in the bottom 25% in terms of exposure (the least exposed to the carbon tax). Note that the ratio starts to increase in 2013, a year prior the reform, among the most exposed plants only. This suggests potential anticipatory effects due to an expected high carbon tax burden.

In parallel, identification also necessitates there 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 (6). Moreover, identification more generally relies on the assumption that industry expects higher carbon stringency in the future, abstracting from shorter-term price volatility. Risk averse and forward-looking industry decision-makers have an incentive to make production and investment decisions to lower immediate and future carbon costs.

5 Results

Table (2) presents the estimated average effects of exposure and expected exposure to the carbon tax reform on various plant-level energy use and employment outcomes, based on Equation (5). Under the baseline specification (column **i**), a 10 percentage point (pp) increase in exposure to the french carbon tax is associated with a 2.03 pp increase in the percentage share of electricity over fossil fuel use. The coefficient is statistically significant at the one percent level. The increase in this ratio is more likely driven by a decrease in total energy use than by an increase in electricity use levels. A 10 pp increase in exposure is associated with statistically significant drop in total energy use (2.59%) and a weakly significant increase in electricity use (1.94%).

The average effect of exposure on fossil fuel levels is negative but not statistically significant. Nevertheless, exposure is significantly associated with a drop in the percentage share of fossil fuels (excluding natural gas) over total fossil fuels, as well as a weakly significant drop in fossil fuel (other than natural gas) levels and in the amount of carbon emissions from fossil fuel use. Among fossil fuels, natural gas emits the least amount of carbon emissions per unit of energy. Hence results suggest that plants are switching across energy fossil fuel inputs towards natural gas to lower current and future tax costs. As a result, the carbon intensity of total fossil fuel significantly decreases given the relative larger share of less carbon intensive natural gas. Notwithstanding the above, exposure is not associated with a statistically significant effect on the carbon intensity of total energy use, indicating that the composition of the mix of energy sources might not have changed enough to significantly lower the carbon intensity of all energy inputs in aggregate.

Finally, while exposure is not significantly associated a change in plant employment levels on average, it is associated with a significant drop in the ratio of total energy use over employment. The decrease in this ratio suggests plant-level general improvements in terms of energy efficiency and costs savings. The lower ratio indicates plants are using less energy per employee on average, which could be due to the adoption of more energy-efficient technologies and optimized production processes. Note that in France, the decline in industrial emissions has largely been driven by improvements in the carbon efficiency of production, with technical advances embedded in investments aimed at reducing pollution and enhancing manufacturing processes (Bornstein and Faquet, 2021; Faquet, 2021). The ratio also suggests cost savings to the extent that energy consumption and costs can represent a major operational expense in manufacturing.

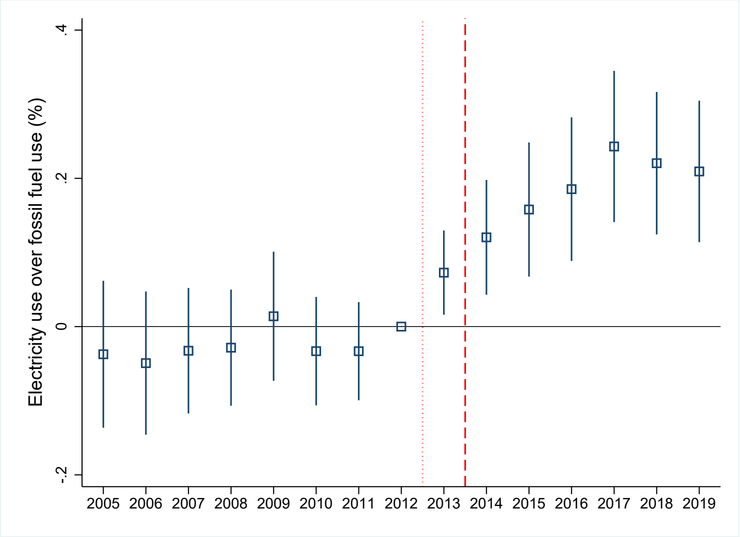
Table 2: Average DiD effects of exposure to carbon tax (%)

Sample Manufacturing plants located in France (n) from 2005 to 2019	Exposure to French carbon tax (%)					
	i	**ii**	**iii**	**iv**	**v**	**vi**
	n = 907 per year		n = 787 per year	n = 453 per year	n = 680 per year	n = 227 per year
	Baseline (continuous)	Binary (median)	Non-null elec. & fossil fuel use	Top & bottom 25% exposure	Omit top 25% exposure	Only top 25% exposure
Energy use and employment ratios						
Electricity over fossil fuel use (%)	.203***	3.980***	.128***	.229***	.404***	.239*
	(.0385)	(.988)	(.0367)	(.0470)	(.0680)	(.122)
Fossil fuels [excl. natural gas] over total fossil fuel use (%)	-.168***	-1.950	-.135**	-.185**	-.0580	-.393**
	(.0607)	(1.225)	(.0643)	(.0743)	(.0857)	(.190)
Carbon intensity of fossil fuel use (log)	-.000641***	-.0121**	-.000534**	-.000825***	-.000322	-.000843
	(.000214)	(.00516)	(.000225)	(.000264)	(.000370)	(.000613)
Carbon intensity of total energy use (log)	-.00169	-.00906	-.00181	-.00374*	-.00663*	-.00451
	(.00171)	(.0447)	(.00176)	(.00203)	(.00372)	(.00328)
Total energy use over employment (log)	-.00240**	-.0576**	-.00160	-.00272**	-.00550***	-.00216
	(.00103)	(.0253)	(.00110)	(.00136)	(.00191)	(.00402)
Energy use and employment levels						
Electricity use (log)	.00194*	.0199	.00195	.00174	.000445	.00793**
	(.00106)	(.0250)	(.00119)	(.00134)	(.00179)	(.00385)
Fossil fuel use (log)	-.00292	-.0433	-.00371*	-.00476*	-.0118***	-.00478
	(.00207)	(.0547)	(.00218)	(.00253)	(.00417)	(.00621)
Fossil fuel use [excluding natural gas] (log)	-.00974*	-.286**	-.0104*	-.0145**	-.0224**	-.00840
	(.00506)	(.125)	(.00576)	(.00645)	(.00928)	(.0159)
Total energy use (log)	-.00259**	-.0597**	-.00244**	-.00259*	-.00565***	-.00193
	(.00110)	(.0257)	(.00114)	(.00152)	(.00212)	(.00419)
Tons of carbon emissions from fossil fuel use (log)	-.00356*	-.0555	-.00424**	-.00559**	-.0121***	-.00563
	(.00205)	(.0542)	(.00215)	(.00253)	(.00413)	(.00606)
Employment (log)	-.0000193	-.00203	-.000840	.000126	-.000152	.000235
	(.000716)	(.0201)	(.000768)	(.000928)	(.00149)	(.00207)

Note: Average effects are estimated based on Equation (5). Under the *baseline* specification, exposure is a continuous variable detailed in Equation (**??**). Under the *binary* specification, exposure is a binary variable detailed in Equation (2. All other specifications are also based on the continuous exposure variable detailed in Equation (1). The sample in the *Non-null elec. & fossil fuel use* specification is composed on plants that consume a non-null amount of both electricity and fossil fuels every year of the panel (2012-2019). The sample in the *Top & bottom 25% exposure* specification only includes firms within the first (Q1) and fourth quartile (Q4) of Equation (3, i.e. plants that are the relatively least exposed and those most exposed to the carbon tax. The sample in the *Omit top 25% exposure* specification only includes within the first to third quartile (Q1, Q2 and Q3) of Equation (3, thereby omitting the relatively most exposed plants. The sample in the *Only top 25% exposure* specification only includes firms in the fourth quartile (Q4) of Equation (3, hence only including the relatively most exposed plants. The ratio *Electricity over fossil fuel use (%)* represents the percentage share of electricity over the sum of electricity and fossil fuel use. Electricity and fossil fuel represents 96% of total energy use, on average. The carbon intensity of fossil fuel use and the carbon intensity of total energy use represent the ratio of tons of carbon emissions from fossil fuel use over total fossil fuels and energy use, respectively. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Employment refers to average employment as at the end of the year as reported by the plant in the Eacei datasets. Standard errors are in parenthesis. Statistical significance is marked with *(0.1 > p-value> 0.05), **(0.05 > p-value > 0.01), ***(p-value < 0.01).

Figures (4) and (5) illustrate the dynamic DiD yearly effects of exposure and expected exposure to carbon tax on various plant-level energy use and job outcomes. Figure (4) indicates that an increase in exposure did not have a statistically significant impact on plants until 2013, a year prior the reform. From 2013, exposure is significantly associated with a rise in the percentage share of electricity over fossil fuel use, and at levels that increase linearly before stabilizing the last two years of the panel.

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

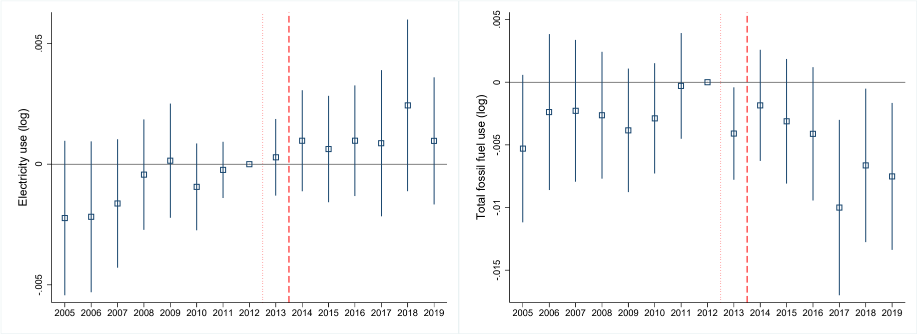


Note: Figure (4) shows results from Equation (4). The percentage share of electricity over fossil fuel use refers to the ratio of electricity use over the sum of electricity and fossil fuel use, where both latter inputs represent around 96% of total energy use on average. The panel includes 907 plants per year. The reference year is 2012. Standard errors are clustered at the plant-level. Confidence intervals are set at the 5% level of significance.

Figure (5) presents additional results under the baseline specification. The most visible post-reform change is the decrease in total energy use with statistically significant effects almost every year. When accounting for dynamic effects, exposure is also associated with a downward trend in fossil fuel use with yearly results statistically significant the last three years.

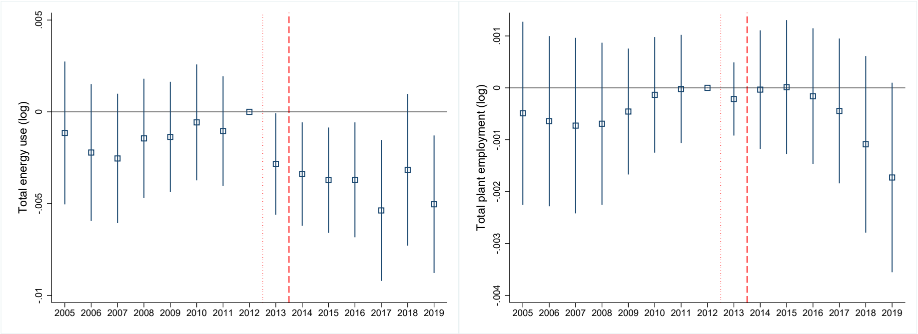
While on average exposure is not associated with a significant change in employment, the dynamic results do show a downward trend in jobs from 2017 onward albeit with no year-by-year significant effects. Marin and Vona (2021) estimate a trade-off among french manufacturing between energy use and emissions and economic goals. Based on a similar panel dataset as in this paper, they conclude that a 10% increase in energy price has a modest albeit statistically significant effect on employment (-0.8%). They additionally conclude that the drop in manufacturing jobs is biased against low-skilled manual workers with no effect on the higher-skilled manual workers, professionals and managers. However, due to data constraints, this paper cannot estimate these heterogeneous effects. They also uncover evidence of an increase in the capital-to-labor ratio at the firm level, suggesting that increases in energy prices, and carbon pricing policies more generally, trigger the adoption of energy saving capital to the detriment of labor. Alternatively, Dussaux (2020) concludes that carbon pricing policies induce manufacturing worker reallocation across firms, leaving total employment unaffected in France. The DiD setup in this paper does not estimate the effects of exposure to the French carbon tax on aggregate manufacturing employment but rather on relative employment effects. Hence, while exposure in the dynamic specification points toward a downward trend in employment outcomes, it also suggests a relative upward trend in jobs among the least exposed, reflecting the hypothesis of reallocation across plants. 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).

Figure 5: Dynamic DiD effects of exposure to carbon pricing on energy use and job outcomes (baseline)



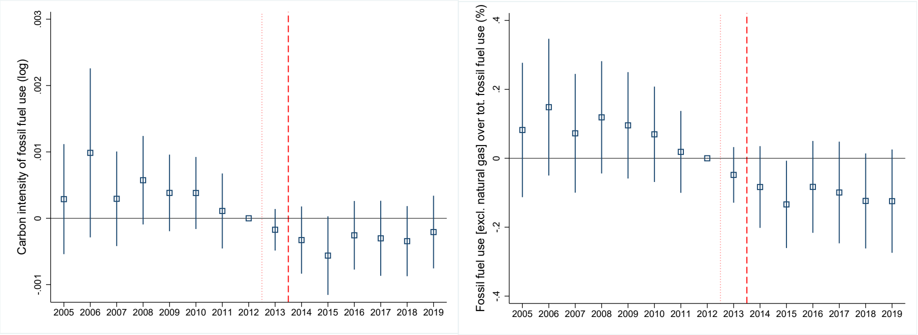
(a) Total electricity use (log)

(b) Total fossil fuel use (log)

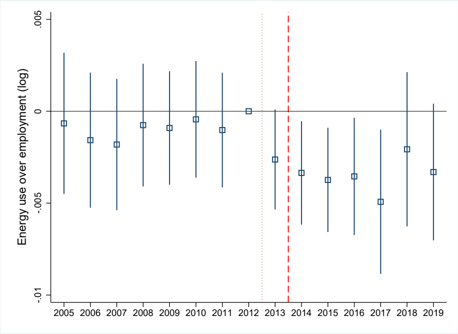


(c) Total energy use (log)

(d) Employment (log)



(e) Carbon intensity of fossil fuel use (log) (f) Fossil fuel [excl. natgas] over tot. fossil fuels (%)



(g) Total energy use over employment (log)

Note: Figure (5) presents dynamic DiD results from Equation (4). The carbon intensity of fossil fuel use and the carbon intensity of total energy use represent the ratio of tons of carbon emissions from fossil fuel use over total fossil fuels and energy use, respectively. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Employment refers to average employment as at the end of the year as reported by the plant in the Eacei datasets. The panel includes 907 plants per year. The reference year is 2012. Standard errors are clustered at the plant-level. Confidence intervals are set at the 5% level of significance.

In Figure (5), the effect of exposure on electricity levels tend to show increasing pre-trends with no significant year-by-year significant effects post-reform, bringing into doubt whether the introduction of the carbon tax had an effect on electricity use more generally. Finally, while coefficients are positive pre-reform and negative post-reform, exposure is not associated with statistically significant year-by-year effects on both the carbon intensity of total fossil fuels and the percentage share of fossil fuels (excluding natural gas) over total fossil fuels. Finally, the dynamic effects of exposure on the ratio of total energy over employment tend to follow those of total energy use.

5.1 Robustness checks

Table (2) also presents the average effects of exposure and expected future exposure to the French carbon tax across various different specifications as robustness checks to the baseline results. The underlying assumption when using the continuous exposure variable, Equation (1), 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, continuous exposure is replaced with a binary exposure variable, or Equation (2) under specification *Binary* (**ii**). Under (**iii**), the sample only includes plants that consume a non-null amount of both electricity and fossil fuels every year of the panel to better ensure they exploit similar capital equipment needed to consume both types of inputs. The three remaining columns in table are based on Equation 3. Specification (**iv**) focuses exclusively on the plants that fall within the bottom (Q1) and top 25% (Q4) of pre-reform exposure to the carbon tax. Results based on continuous exposure verify the extent to which baseline results hold even when comparing the more extreme cases in terms of exposure in the sample. Finally, to examine to extent to which results are driven by different exposure levels, specifications (**v**) and (**vi**) omit and include the top 25% plants (Q4) in terms of their exposure to the carbon tax, respectively.

With regards to average effects, exposure to the French carbon tax is associated with higher shares of electricity over fossil fuel use across all specifications, albeit only at the 10 percent level among the most exposed plants (**vi**). Accordingly, the sample with all plants except the top 25% in terms of exposure (**v**) experience the largest effect: a 10 pp increase in exposure is associated with a 4.04 pp increase in the ratio, a doubling of the effect compared the baseline. Figure (B1) illustrates these results. While both figures (B1c) and (B1d) show a slight pre-trend, the post-policy jump in the relative share of electricity over fossil fuel use is visible and distinct across all graphs. The relatively larger confidence intervals found in Figure (B1e) suggests considerable heterogeneity across the most exposed firms, which could explain the less significant average effect.

Moreover, Figure (B1d), echoing Figure (3b), suggests that the significant pre-reform effect of exposure on firm behavior in 2013 appears to be driven primarily by the most exposed plants. This 2013 effect among the most exposed plants likely reflects anticipatory behavior. At the end of 2012, the French government organized its first multi-stakeholder Environment Conference, where green taxation was a major theme. To meet international climate agreements and national carbon mitigation objectives, the conference advocated for both European carbon pricing and a national carbon excise duty. Consequently, the multi-stakeholder Environment Taxation Committee (*Comité pour la fiscalité écologique*) was established in 2013, tasked with assessing and formulating carbon pricing policy measures to be implemented the following year. Concurrently, in 2011, the EU Commission proposed revising Directive 2003/96/EC to introduce a carbon tax of €20 per tCO_2 on energy use outside the European carbon market (EU-ETS), set to be introduced in 2013 (Cours des Comptes, 2019; Citepa, 2011). In anticipation of higher carbon costs, managers of the most exposed, carbon-intensive industries likely adjusted their production and investment decisions to account for expected future carbon prices.

While the most exposed firms experience a statistically significant increase in electricity on average, dynamic effects in Figure (B2d) suggest pre-trends and Figure (B2) more generally does not discern any noticeable and significant post-reform effects across all specifications that could be attributable to the policy. Moreover, exposure is associated with significant drops in energy use as detailed in Table (2) and illustrated in Figure (B4), albeit the dynamic effects among the most exposed firms (top 25%) are not conclusive.

More generally, the dynamic effects of exposure in the sample encompassing the most exposed plants to tend to showcase large confidence intervals and significant pretrends, rendering difficult the estimation of the effect of exposure among those plants. This could be due to larger variability in how the different plants respond to policy under the carbon tax regime, notwithstanding the anticipatory effects.

Furthermore, Figure (B5d) suggests the downward trend found in job outcomes found in Figure (5d) are largely driven by the most exposed firm (Figure B5e), although average effects remain not statistically significant throughout. With regards to the effect of exposure on the ratio of total energy consumed per job, all average effects are negative and statistically significant, with the exception of plants that consume a non-null amount of electricity and fossil fuels (**iii**) and the most exposed plants (**vi**), likely due to a non-significant effect on total energy use among the latter. Figure (B8) illustrates these effects. Exposure is associated with a statistically significant drop in fossil fuel use among specifications (**iii**), (**iv**), and especially (**v**) in table (2), although a noticeable downward trend in Figure (B3) is found across all specifications (although, again, the yearly effects presented among the most exposed firms remain inconclusive).

Plants that consume a non-null amount of both electricity and fossil fuels experience significant average drops in the carbon intensity of fossil fuel use and in the percentage share of fossil fuels (excluding natural gas) over total fossil fuel use. Their dynamic post-reform effects for these outcomes are also the most distinct and significant relative to other specifications. Figures (B6) and (B7) illustrate the event study results for both outcomes. This finding could be attributed to the likelihood that these plants are better positioned to optimize their energy mix in response to carbon pricing policies. They possess established infrastructure and capital equipment that supports the consumption of both electricity and fossil fuels, allowing them to more effectively adjust their energy strategies and lower their expected carbon tax burden when necessary.

Figures (B9) and (B10) present the average effects of exposure to the french carbon tax within each manufacturing sector based on Equation (5). Exposure to the french carbon tax is significantly associated with an increase in the electricity to fossil fuel use ratio in the chemicals, basic pharmaceuticals, other non-metallic minerals and machinery and equipment n.e.c., with positive effects across almost all sectors. Nevertheless, the figure does not uncover a significant effect on total electricity use, total energy use and on job outcomes. Most effects on total fossil fuel use are negative, albeit not statistically significant from zero, with the exception of the machinery sector. On the other hand, the motors and transport equipment sector experience a significant increase in fossil fuel use. Only fabricated metals experience a significant drop in the carbon intensity of its fossil fuel use, as well as in the share of fossil fuels (excluding natural gas) over total fossil fuels. Finally, only the wood, paper and printing sectors experience a significant drop in the energy consumption per employee. The analysis reveals variations in policy impact across manufacturing sectors. Findings suggest the importance of accounting for sector-level heterogeneity when evaluating policy that affects corporate outcomes, highlighting the value in considering these differences when designing such policies.

Overall, and accounting for both average and event study DiD effects across all specifications, exposure and expected exposure to the carbon tax compelled manufacturing plants to increase their use of electricity as inputs relative to fossil fuel use, as the former is not subject to the tax. This increase is more likely driven by a decrease in total energy use, and particularly fossil fuel use, as opposed to an increase in electricity use in levels. Two non-mutually exclusive strategies to lower the carbon tax burden stand out among manufacturing plants: (1) general improvements in terms of energy efficiency and costs savings as evidenced in the use of less total energy per employee under the carbon tax regime; (2) input shifts across fossil fuels to the benefit of natural gas use that lead to cuts in the carbon intensity of fossil fuel use and contribute to a drop in tax base of a carbon tax (carbon emissions). Nevertheless, input shifts are not large enough so as for the effect on the carbon intensity of total energy use to be significant. Furthermore, and despite the cuts in total energy use, evidence does not suggest that exposure is associated with job losses on average. This finding mitigates concerns about a decline in corporate profitability due to the carbon tax.

Alternate exposure variable

Table (B1) presents average DiD results based on an alternate measure of exposure: the pre-reform average amount of estimated carbon costs, estimated in Equation (3.2). The variable is in log form to account for outliers. Akin to Figure (2), Figure (A3) shows a negative near-linear relationship between electricity use relative to fossil fuels, where the former is not subject to the carbon tax, and the estimated growth in carbon costs due to the reform. Hence, as expected, relatively larger fossil fuel consumers estimate higher future carbon costs compared to larger electricity users.

$$\text{Alternate Exposure}_{i,<2014} \equiv \text{Estimated carbon costs}_{i,<2014} \tag{6}$$

Overall, results are akin to conclusions found in column (**i**) of Table (2), although the effect on total energy use is no longer statistically significant. On average, a 10% increase in carbon costs is associated with a statistically significant 0.15 pp increase in the ratio of electricity over fossil fuels, a magnitude much smaller than that found in column (**i**) in Table (2). Figure (B11) additionally presents the dynamic effects on energy use and employment outcomes. Pre-trends are not as flat as in Figure (5) for several outcomes. Note that when exposure is Equation (1), estimated carbon costs are relative to the total energy bill. The assumption is that plants are primarily concerned with how the carbon tax impacts their overall energy costs as opposed to just the cost of fossil fuels. Additionally, normalizing carbon costs by total costs could help mitigate plant heterogeneity, which may be a driver of the pre-trends shown when exposure is not normalized.

Including EU-ETS in the sample

The EU-ETS is a cap-and-trade system that sets a price on carbon through the trading of emission allowances. Set up in 2005, it is considered a cornerstone of EU climate policy. Participation in the system is mandatory for power plants and industrial firms with a rated thermal input exceeding 20 megawatts (MW), as well as when exceeding specific capacity thresholds. Carbon prices faced by EU-ETS participants have been historically low, roughly below €10 per tCO_2 between 2013 and 2018. Since 2018 emission carbon permit prices have steadily increased following a revision of the Directive (Ministry of the Environment, 2024). This effectively implies that non-EU-ETS participants faced higher carbon prices through the carbon tax than EU-ETS participants did through the EU-ETS during the period of analysis in this paper. Moreover, recent empirical evidence reveals that participants in the EU-ETS tend to experience improvements in economic performance (Löschel, Lutz and Managi, 2019) in addition to improvements in environmental outcomes (Dechezleprêtre, Nachtigall and Venmans, 2023; Colmer et al., 2024; Germeshausen, 2020).

EU-ETS participants are very large firms. Table (A2) presents summary statistics comparing the baseline sample that excludes EU-ETS participants and the larger sample of firms that include them. Overall, EU-ETS plants are larger, both in respect to plant-level energy-related and firm-level economic characteristics. They also add more heterogeneity to the sample as reflected by the relatively higher standard deviations. Table (B1) also presents average results based on a sample inclusive of plants identified as EU-ETS participants (see section 3.1). A 10 percentage point (pp) increase in exposure is statistically associated with a 0.853 pp increase in the share of electricity over fossil fuel use, an effect at a lower magnitude compared to the baseline results in column (**i**) in Table (2). While the effects on electricity and on fossil fuel use separately are statistically significant, exposure to the carbon tax is no longer associated with cuts in fossil fuels other than natural gas, nor in total energy use. Figure (B12) graphs the dynamic effects. While post-treatment effects are akin to those found in several graphs in Figure (5), the graphs more generally tend to show pre-trends and large confidence intervals. The focus of this study is on the effects of the French carbon tax, while trying to mitigate any bias that may emanate from EU-ETS treatment effects. As a result, findings may indicate that the model used in this paper may not be suitable for capturing the experiences of larger firms, which face a different and smaller carbon price under the cap-and-trade system (during the years covered by the panel) compared to firms that do not participate due to their size.

6 Discussion

Energy Transition for Green Growth Act

The carbon tax is not a stand-alone environmental 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*)[4]. It is also noteworthy

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[4] 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

that with Article 173 of the LTECV France became the first country to require listed companies and institutional investors to report on their exposure to financial risks related to climate change (UNEPFI, 2016)[5]. 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. Note that in 2019 (the last year of the panel) following the yellow vests protests, the government froze the actual carbon tax rate to its 2018 rate, putting an end to its actual trajectory. Clear and predictable carbon tax policy provides certainty for businesses, helping them plan and make informed decisions about ongoing and future energy use and investment decisions.

Overlapping policies
As noted in Section (4.1), 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 main 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. More generally, it is possible that interactions between the two pricing mechanisms could indirectly influence the behavior of firms, particularly through market dynamics or cost pass-throughs. 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 (A2a) 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 electricity tax reform.

Energy prices
Changes in relative prices of different energy fuels may drive results, inducing different substitution patterns depending on past energy mixes. In addition to Figure (A2a), Figure (A2) also presents the evolution of the average cost of natural gas, fossil fuels and fossil fuels excluding natural gas across highly exposed and lesser exposed plants to French carbon tax. Overall, the figures do not suggest that plants were exposed to significantly different average costs of energy fuels, suggesting that differential fuel prices are not a major confounding factor. This mitigates concerns that the findings are

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Industry Council, 2021b; National Industry Council, 2021c).

[5] Using a DiD specification, Mésonnier and Nguyen (2022) 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 32% in holdings of fossil fuel securities after December 2015 among institutional investors in France.

driven by fuel price differentials rather than the imposition of the carbon tax and the anticipation of an increasingly stringent carbon pricing regime

Comparison with Marin and Vona (2021) and Dussaux (2020)
Both Marin and Vona (2021) and Dussaux (2020) examine the effects of energy prices on French plant and firm-level energy and economic outcomes, respectively, as measures for carbon taxation and increasingly stringent carbon pricing (see section 1.1). They conclude that increases in energy costs reduces energy use (5.2% - 5.9%) and carbon emissions (11.4% - 9.2%), particularly driven by a reduction in fossil fuels (6.5%) with no statistically significant effect on electricity use in Dussaux (2020). They also uncover evidence drops in manufacturing jobs (0.8% - 2.2%), albeit no significant effect on employment in aggregate in Dussaux (2020). This paper similarly shows that increased exposure is associated with lower energy consumption, primarily driven by reductions in fossil fuels, especially the more carbon-intensive ones, with no significant effect on electricity use. However, the magnitude of the effects in this study is smaller. For example, a 10 percentage point (pp) increase in exposure is associated with an average decrease of 2.59% in total energy use, roughly 3 percentage points lower than the findings in previous studies. Additionally, this paper does not find a significant effect on manufacturing jobs on average, though dynamic effects suggest a downward trend in some cases post-reform. These differences may be due to the different measures of exposure used in this paper, as well as the distinct empirical strategies, including pooled and dynamic effects.

Upper-bound estimates
Note that all energy consumers face the carbon tax at different levels of exposure contingent on energy use and their eligibility to preferential tax treatment. The estimation of preferential tax treatment for each plant is beyond the scope of this paper. Hence findings may be considered upper-bound estimates, to the extent that this paper effectively assumes full exposure to the tax. Notwithstanding the above and given the original long-term trajectory of the French carbon tax, the analysis posits that expectations of increasingly higher future carbon prices also drive corporate behavior so as to lower future cost burden.

7 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. Exposure and expectations of increased exposure to carbon pricing are positively associated with a higher proportion of electricity use relative to fossil fuels. A 10 percentage point (pp) increase in exposure to the french carbon tax is associated with a 2.03 pp increase in the percentage share of electricity over fossil fuel use. This shift is likely driven by a decrease in total energy use, particularly in the consumption of fossil fuels, resulting in less carbon emissions emitted. However, there is a lack of evidence to suggest that exposure led to an increase in electricity consumption, a fuel not subject to the carbon tax. Instead, findings uncover evidence of possible input shifting across fossil fuels, to the benefit of less carbon-intensive natural gas, resulting in a lower carbon intensity of fossil fuel use. Finally, evidence does not suggest that exposure is associated with job losses on average, undercutting the premise that a carbon tax is associated with losses in corporate profitability.

Risk-averse and forward-looking managers and decision-makers 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. As a result, reliance on low-carbon electricity power for production purposes increases under the carbon tax regime. Manufacturing plants likely adopted two strategies to reduce their carbon tax burden: (1) improve energy efficiency and cutting costs, as shown by reduced total energy use per employee; (2) shift from more carbon-intensive fossil fuels to natural gas, thereby lowering the carbon intensity of fossil fuel use. This paper underlines the fact that a carbon tax encourages a narrowing of its tax base.

Policy makers should encourage further investments in energy-efficient technologies and practices, as well as in infrastructure development so as to facilitate the switch towards less carbon-intensive fuels. Targeted support and incentives are necessary to account for sector-level differential impacts of a carbon tax and to achieve desired national environmental and economic goals. Given the increased reliance on electricity power for continued production, this paper also raises questions regarding the adequacy of the current grid infrastructure and the overall impact on grid stability and reliability. While beyond the scope of this paper, future research could also explore whether firms reorganize their operations in response to long-term carbon cost expectations, including potential offshore expansions. 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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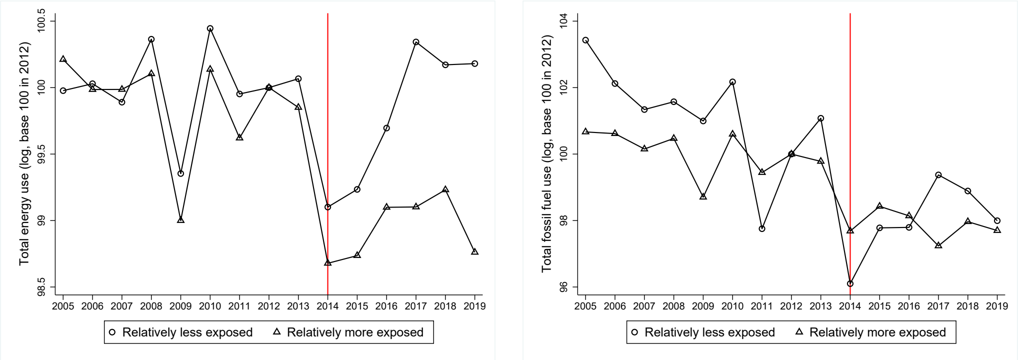
A Descriptive statistics

Table A1: Summary statistics by exposure level (quartiles) in 2005

	Exposure to French carbon tax							
	Q1 Bottom 25% Least exposed		Q2 25%-50% Relatively less exposed		Q3 50%-75% Relatively more exposed		Q4 Top 25% Most exposed	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Estimated increase in energy costs due to carbon tax (%)	5	3	15	3	25	3	41	10
Electricity use over fossil fuel use (%)	86	13	62	12	45	10	28	13
Total electricity use (‘100 toe)	12	25	8	10	9	16	7	12
Total fossil fuel use (‘100 toe)	2	6	5	6	9	11	22	37
Electricity use over total energy use (%)	79	20	61	13	45	10	27	13
Fossil fuel use over total energy use (%)	14	13	38	12	54	10	71	14
Natural gas use over total fossil fuel use (%)	54	48	72	42	85	32	81	35
Fossil fuel use [excl. natural gas] (toe)	43	178	55	121	60	152	237	737
Fossil fuel use [excl. natural gas] over total fossil fuel use (%)	38	46	27	41	15	32	19	35
Total energy use (‘100, toe)	17	35	13	16	19	25	30	50
Total energy costs (‘1 000, €)	834	1 502	639	765	846	1 224	1 056	1 475
Employment (#)	386	463	396	361	355	303	246	266
Tons of carbon emissions from fossil fuel use (tC02)	659	1 656	1 312	1 656	2 563	2 996	6 106	10 197
Carbon intensity of fossil fuel use	3	0	3	0	3	0	3	1
Carbon intensity of total energy use	0	0	1	0	2	0	2	0
Average cost of electricity use (€ per MWh)	55	9	57	11	57	10	56	10
Average cost of natural gas (€ per MWh)	17	15	21	12	24	10	22	11
Firm-level sales (‘1 000 000)	152	245	236	440	228	559	136	353
Firm-level total net operating income (‘1 000 000)	10	25	16	54	18	68	8	19
Firm-level gross assets (‘1 000 000)	226	494	347	862	321	996	158	353
Export over total revenues (%)	36	29	34	29	38	28	34	28

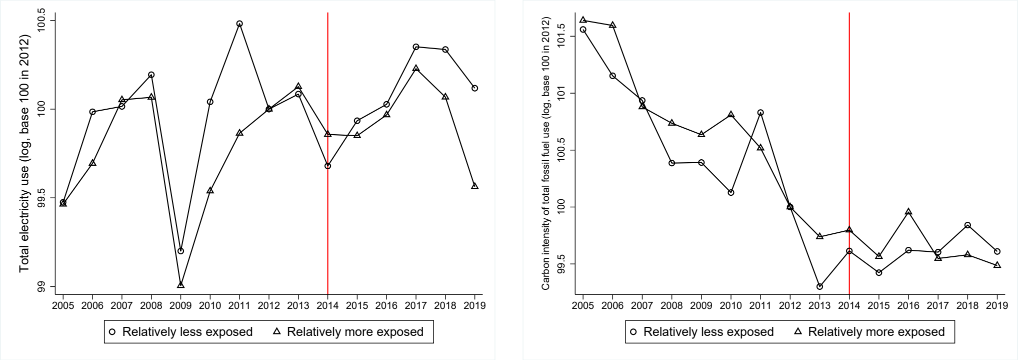
Note: Values are rounded to the nearest integer. Exposure status is defined in Equation (3). The electricity use over energy use ratio refers to the ratio of electricity use over the sum of electricity and fossil fuel use, with electricity and fossil fuel use representing around 96% of total energy use on average. 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. Energy use and plant-level variables come from EACEI. Firm-level variables come from tax returns. The balanced panel includes 907 plants per year that do not participate in the European cap-and-trade system.

Figure A1: Parallel trends - additional energy use and job outcomes



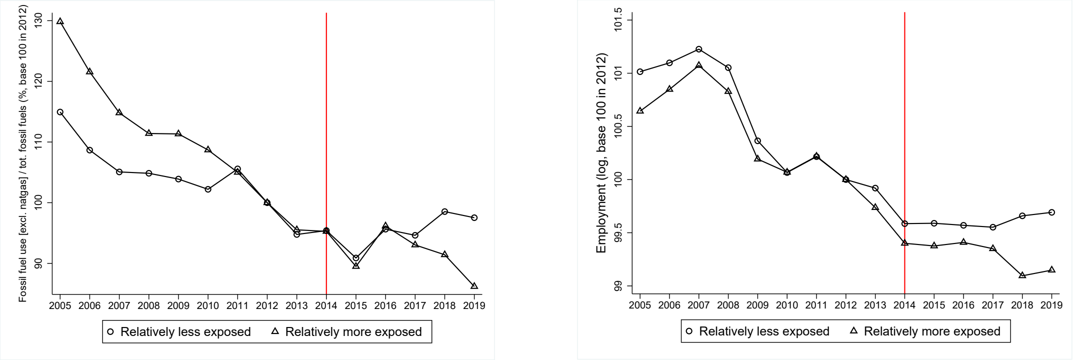
(a) Total energy use (log)

(b) Fossil fuel use (log)



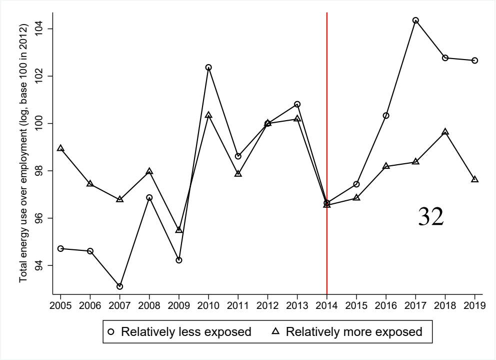
(c) Electricity use (log)

(d) Carbon intensity of fossil fuel use (log)



(e) Fossil fuels (excl. natgas) over tot. fossil fuel use

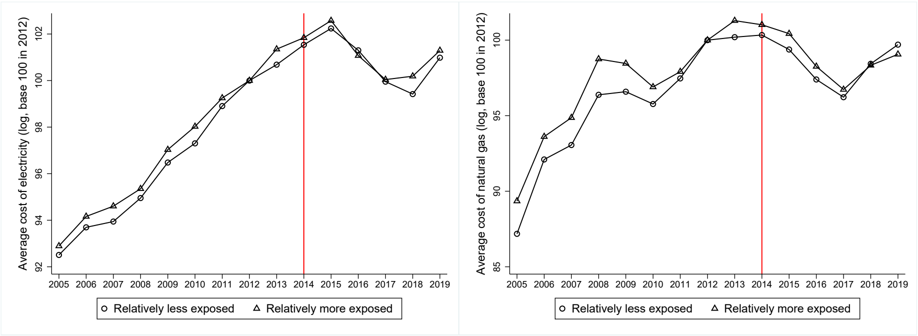
(f) Employment



(g) Total energy use over employment

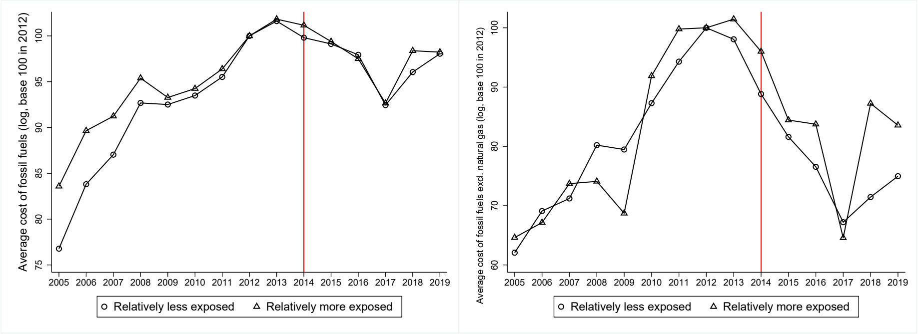
Note: Exposure level is determined at its median value, as detailed in Equation (2). Trends are indexed to year 2012.

Figure A2: Parallel trends - average cost of energy fuels



(a) Electricity

(b) Natural gas

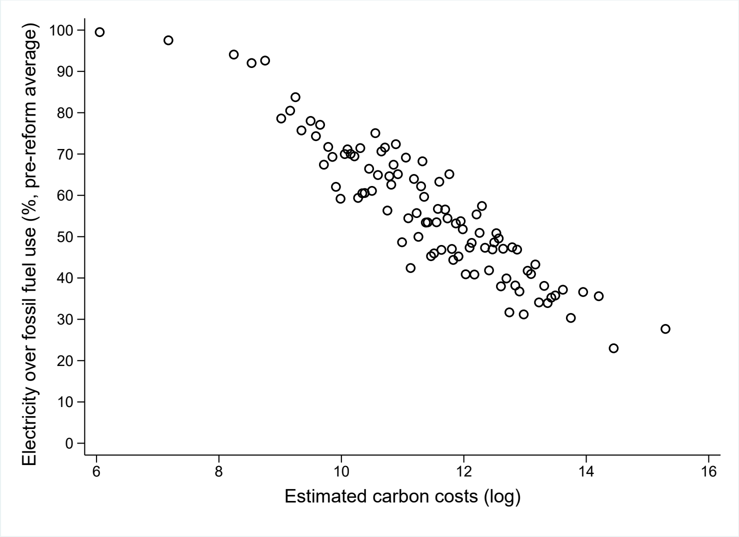


(c) Fossil fuels

(d) Fossil fuels, excl. natural gas

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

Figure A3: Correlation between electricity use over fossil fuel use (%) and the estimated increase in carbon costs due to the carbon tax reform (%)



Note: Figure (A3) presents a binned scatter-plot. The x-axis refers to Equation (6). The y-axis refers to the pre-reform ($< 2014 : 2005$-2013) percentage share of electricity over fossil fuel use.

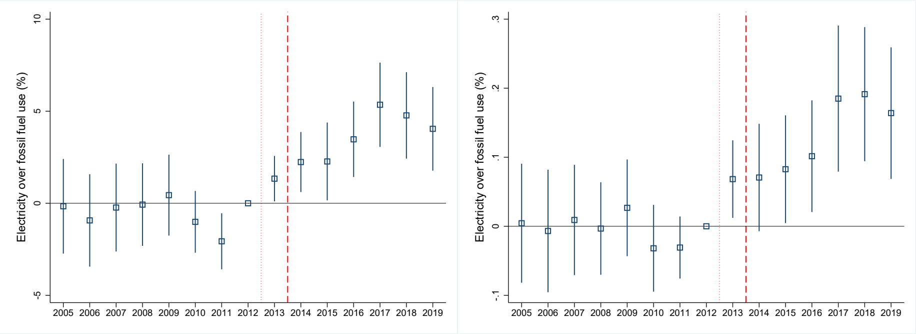
Table A2: Summary statistics in 2005: baseline sample vs sample including EU-ETS plants

	Sample			
	Baseline n = 907 per year		Incl. EU-ETS n = 1 185 per year	
	Mean	St. Dev.	Mean	St. Dev.
Estimated increase in energy costs due to carbon tax (%)	21	14	30	32
Electricity use over fossil fuel use (%)	55	25	51	26
Total electricity use (‘100 toe)	9	17	28	97
Total fossil fuel use (‘100 toe)	10	21	96	979
Electricity use over total energy use (%)	53	24	47	26
Fossil fuel use over total energy use (%)	44	25	48	26
Natural gas use over total fossil fuel use (%)	73	41	71	42
Fossil fuel use [excl. natural gas] (toe)	99	399	6 826	95 637
Fossil fuel use [excl. natural gas] over total fossil fuel use (%)	24	39	27	40
Total energy use (‘100, toe)	20	34	143	1 059
Total energy costs (‘1 000, €)	844	1 283	3 336	18 967
Employment (#)	346	361	381	456
Tons of carbon emissions from fossil fuel use (tC02)	2 660	5 828	37 492	436 040
Carbon intensity of fossil fuel use	3	1	3	1
Carbon intensity of total energy use	1	1	1	1
Average cost of electricity use (€ per MWh)	56	10	54	11
Average cost of natural gas (€ per MWh)	21	12	20	13
Firm-level sales (‘1 000 000)	188	419	320	694
Firm-level total net operating income (‘1 000 000)	13	46	25	65
Firm-level gross assets (‘1 000 000)	263	728	514	1 226
Export over total revenues (%)	36	28	36	29

Note: Values are rounded to the nearest integer. Exposure status is defined in Equation (2). The electricity use over energy use ratio refers to the ratio of electricity use over the sum of electricity and fossil fuel use, with electricity and fossil fuel use representing around 96% of total energy use on average. 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. Energy use and plant-level variables come from EACEI. Firm-level variables come from tax returns. The balanced panel includes 907 plants per year that do not participate in the European cap-and-trade system.

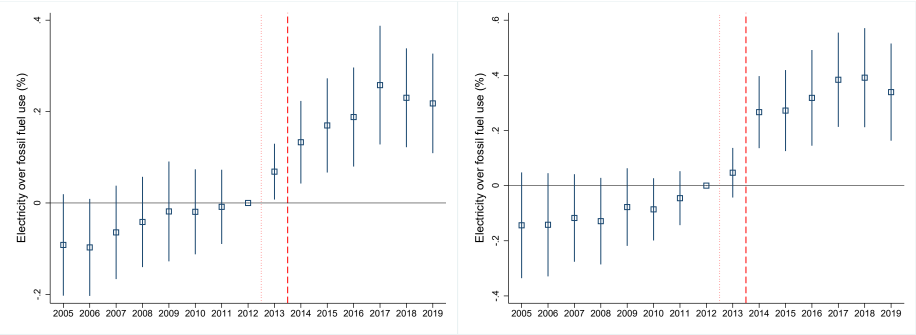
B Results

Figure B1: Dynamic DiD effects of exposure to carbon pricing on the percentage share of electricity over fossil fuel use (%)



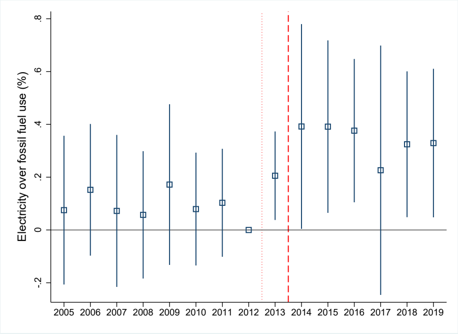
(a) Binary

(b) Non-null elec. & fossil fuel use



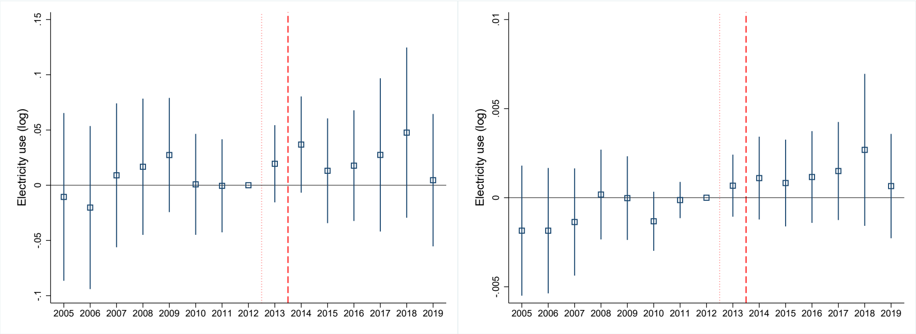
(c) Top & bottom 25%

(d) Omit top 25%



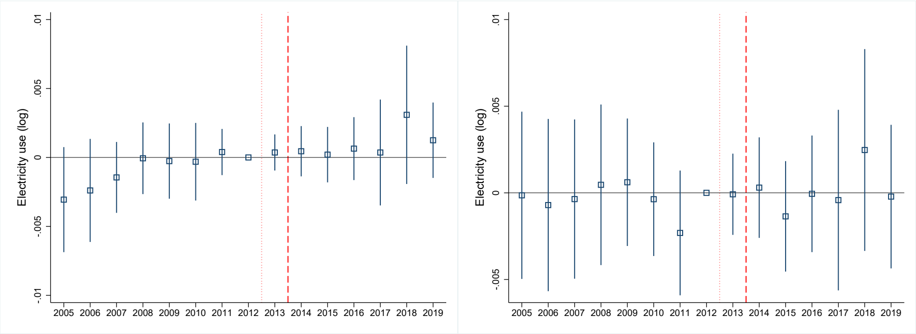
(e) Only top 25%

Figure B2: Dynamic DiD effects of exposure to carbon pricing on total electricity use (log)



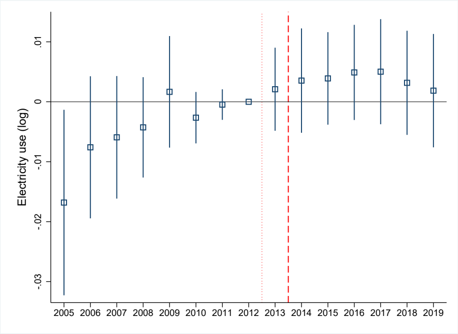
(a) Binary

(b) Non-null elec. & fossil fuel use



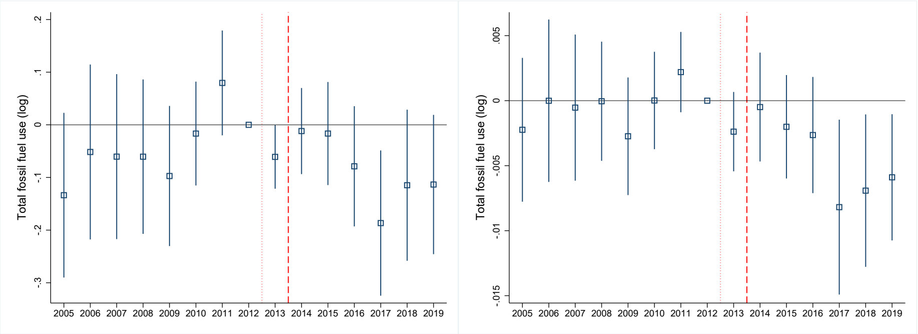
(c) Top & bottom 25%

(d) Omit top 25%



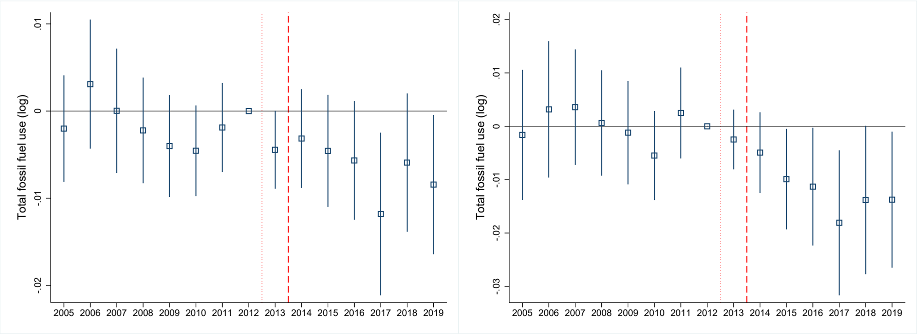
(e) Only top 25%

Figure B3: Dynamic DiD effects of exposure to carbon pricing on total fossil fuel use (log)



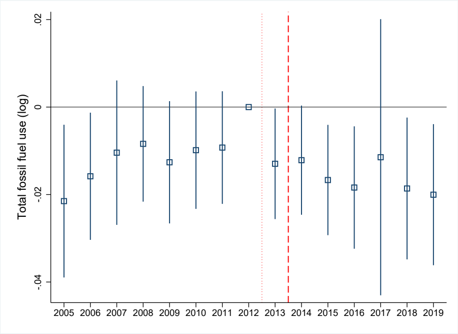
(a) Binary

(b) Non-null elec. & fossil fuel use



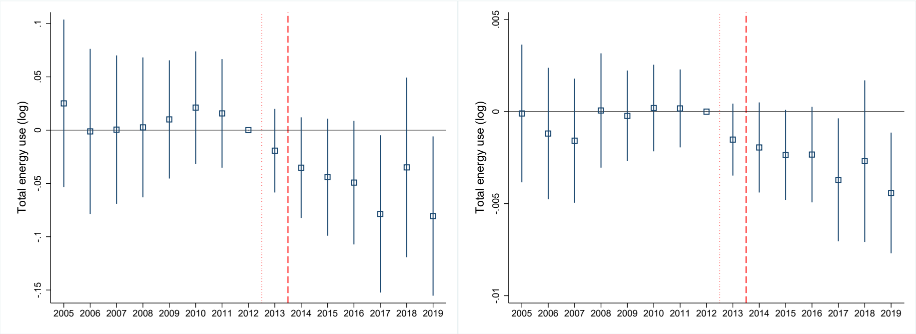
(c) Top & bottom 25%

(d) Omit top 25%

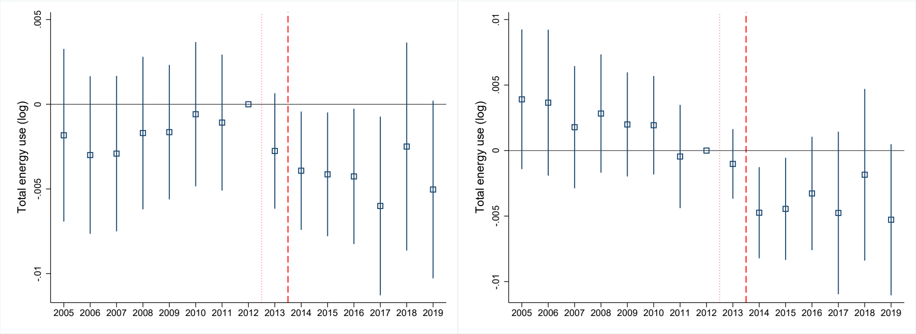


(e) Only top 25%

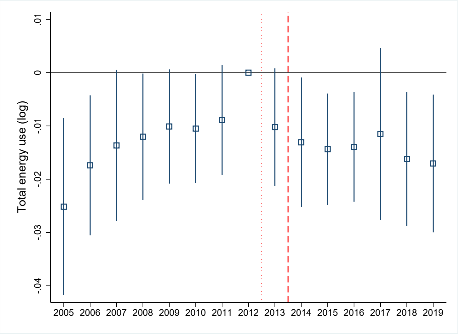
Figure B4: Dynamic DiD effects of exposure to carbon pricing on total energy use (log)



(a) Binary (b) Non-null elec. & fossil fuel use

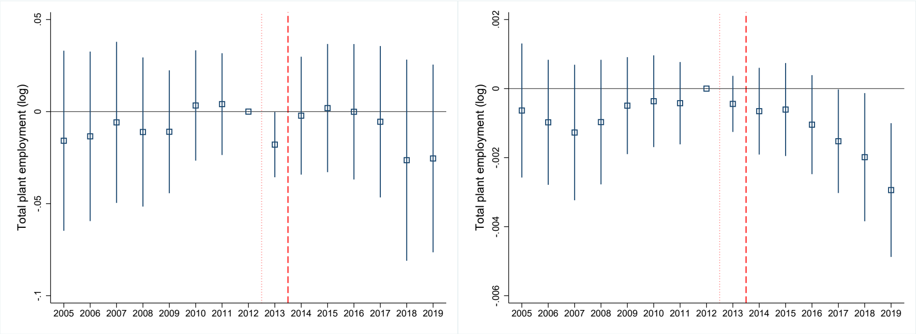


(c) Top & bottom 25% (d) Omit top 25%



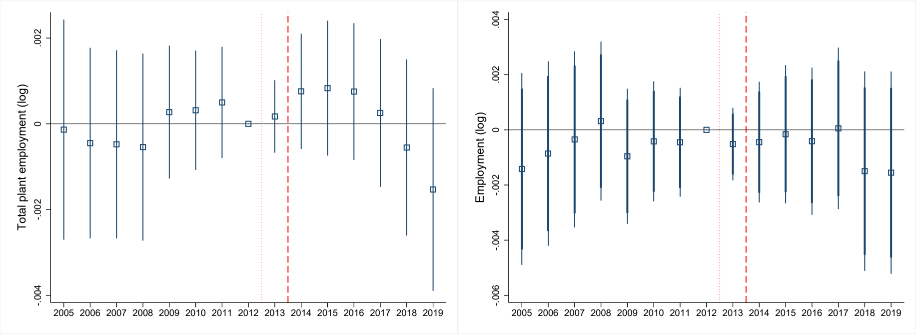
(e) Only top 25%

Figure B5: Dynamic DiD effects of exposure to carbon pricing on employment levels (log)



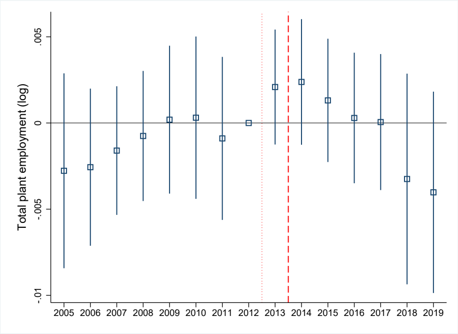
(a) Binary

(b) Non-null elec & fossil fuel use



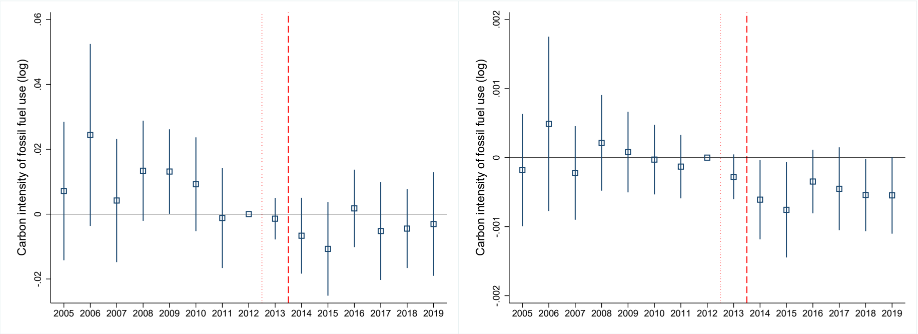
(c) Top & bottom 25%

(d) Omit top 25%

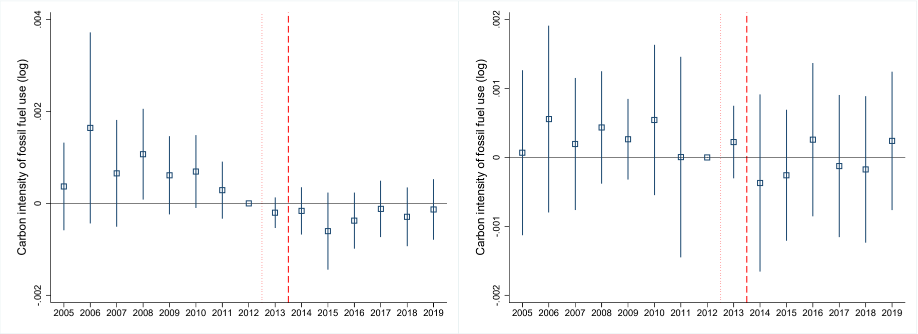


(e) Only top 25%

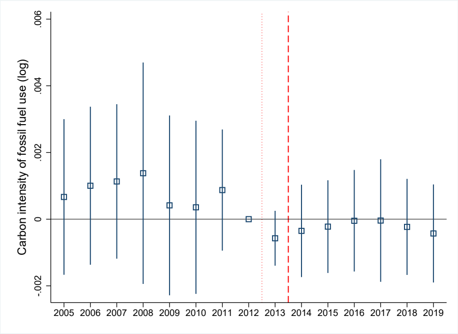
Figure B6: Dynamic DiD effects of exposure to carbon pricing on the carbon intensity of fossil fuel use (log)



(a) Binary (b) Non-null elec. & fossil fuel use

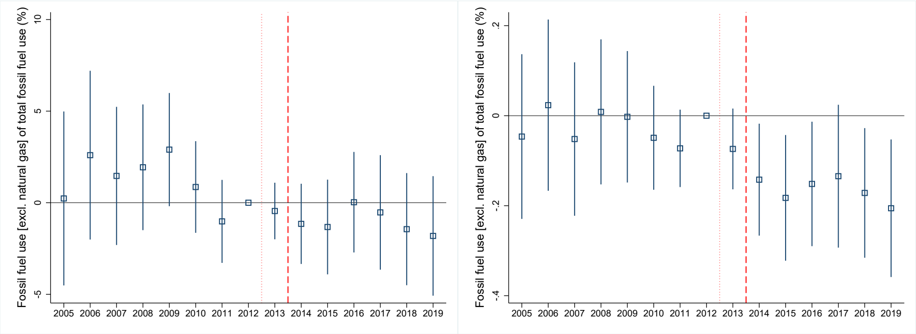


(c) Top & bottom 25% (d) Omit top 25%



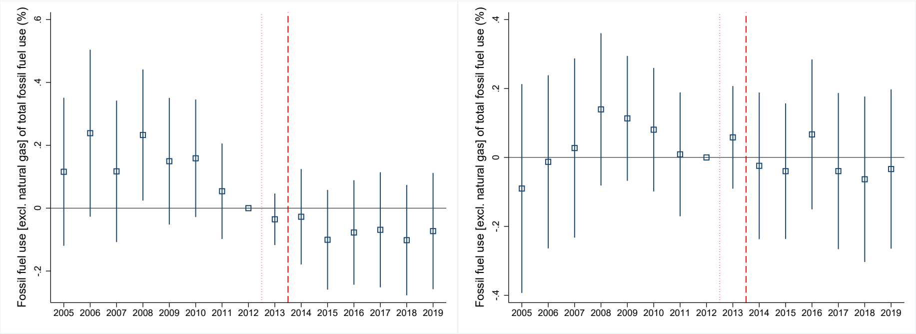
(e) Only top 25%

Figure B7: Dynamic DiD effects of exposure to carbon pricing on the percentage share of fossil fuels (excl. natural gas] over total fossil fuel use (%)



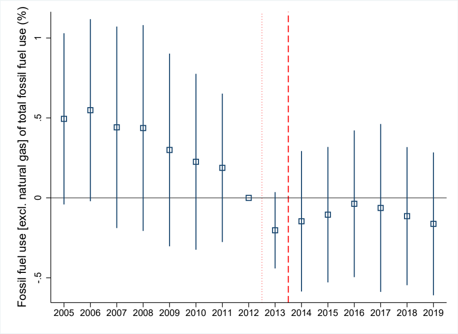
(a) Binary

(b) Non-null elec. & fossil fuel use



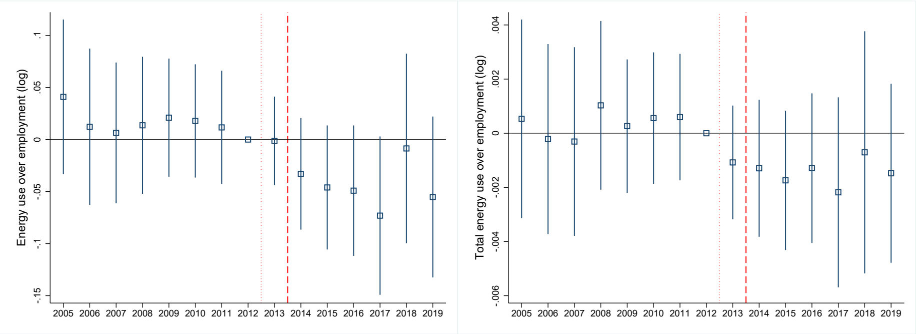
(c) Top & bottom 25%

(d) Omit top 25%



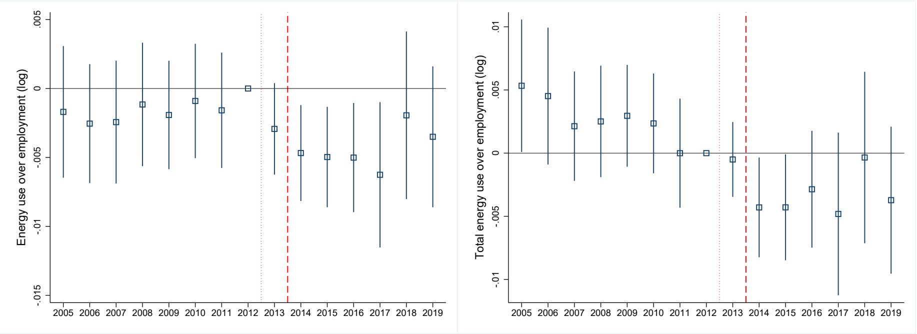
(e) Only top 25%

Figure B8: Dynamic DiD effects of exposure to carbon pricing on total energy use over employment (log)



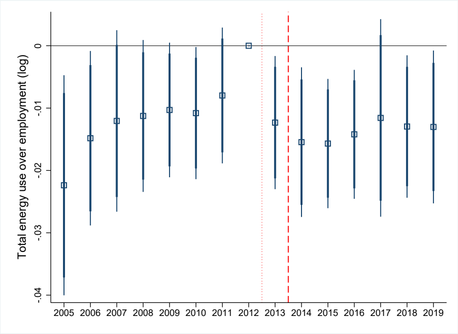
(a) Binary

(b) Non-null elec. & fossil fuel use



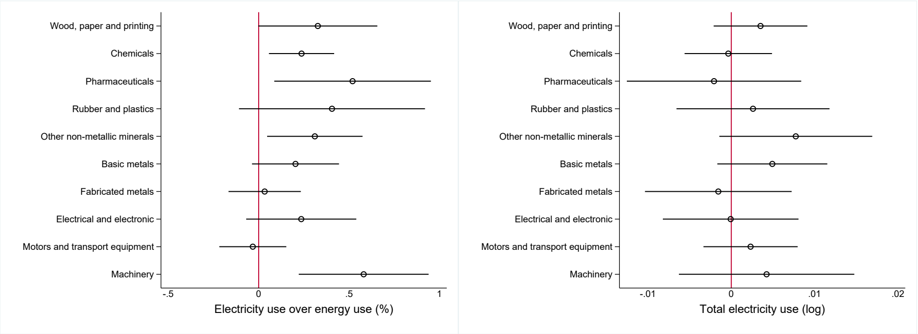
(c) Top & bottom 25%

(d) Omit top 25%



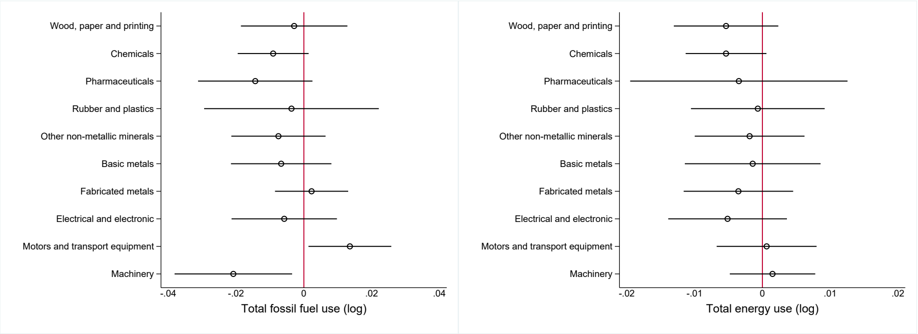
(e) Only top 25%

Figure B9: Average DiD effects of exposure to carbon pricing on energy use and job outcomes within manufacturing sectors



(a) Electricity over fossil fuel use (%)

(b) Total electricity use (log)

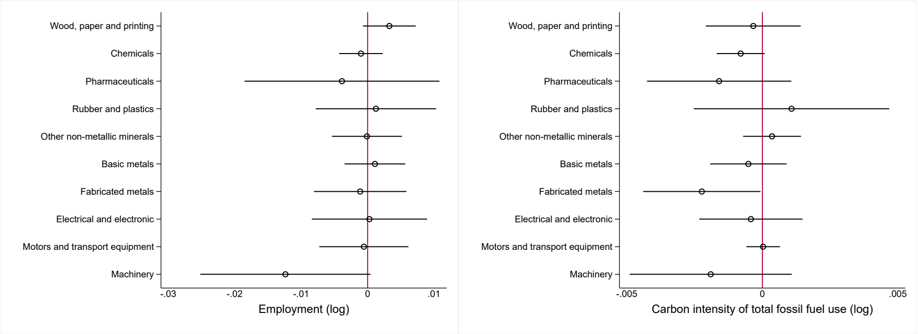


(c) Total fossil fuel use (log)

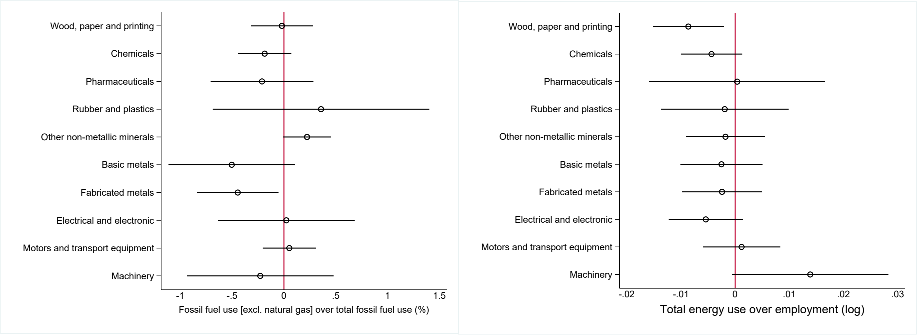
(d) Total energy use (log)

Note: Figure (B9) presents average DiD results from Equation (5). It applies the regression on sub-samples of plants within the same manufacturing sector. Electricity over fossil fuel use refers to the ratio of electricity over the sum of electricity and fossil fuel use. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Standard errors are clustered at the plant-level. Confidence intervals are set at the 5% level.

Figure B10: Average DiD effects of exposure to carbon pricing on energy use and job outcomes within manufacturing sectors (bis)



(a) Employment (log) (b) Carbon intensity of fossil fuel use (log)



(c) Fossil fuel [excl. natgas] over tot. fossil fuels (%) (d) Total energy use over employment (log)

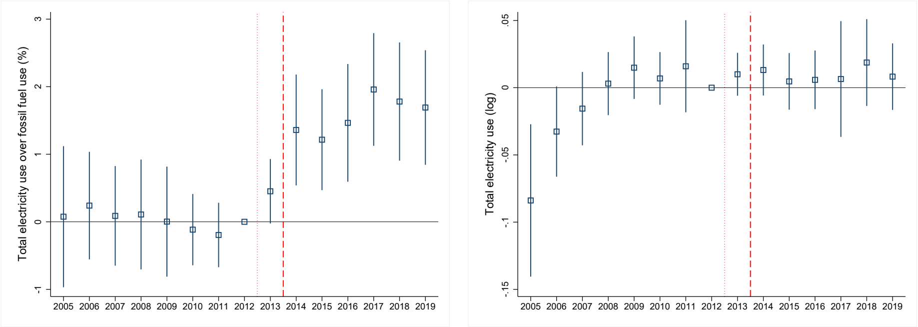
Note: Figure (B9) presents average DiD results from Equation (5). It applies the regression on sub-samples of plants within the same manufacturing sector. The carbon intensity of fossil fuel use and the carbon intensity of total energy use represent the ratio of tons of carbon emissions from fossil fuel use over total fossil fuels and energy use, respectively. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Employment refers to average employment as at the end of the year as reported by the plant in the Eacei datasets. Standard errors are clustered at the plant-level. Confidence intervals are set at the 5% level.

Table B1: Average DiD effects of exposure to carbon tax reform (additional results)

	Exposure to French carbon tax	
Sample		
Manufacturing plants located in France (2005-2019) per year (n)	Baseline n = 907	Incl. EU-ETS n = 1 185
Exposure measure	Estimated carbon costs (log)	Baseline (%)
Energy use and employment ratios		
Electricity over fossil fuel use (%)	1.500***	.0853***
	(.317)	(.0223)
Fossil fuels [excl. natural gas] over total fossil fuel use (%)	-1.615**	-.0224
	(.780)	(.0280)
Carbon intensity of fossil fuel use (log)	-.00682**	-.000186
	(.00269)	(.000129)
Carbon intensity of total energy use (log)	-.0261	-.00248**
	(.0280)	(.00105)
Total energy use over employment (log)	-.0208*	-.00102*
	(.0119)	(.000520)
Energy use and employment levels		
Electricity use (log)	.0182*	.00119**
	(.0104)	(.000469)
Fossil fuel use (log)	-.0368	-.00261**
	(.0294)	(.00120)
Fossil fuel use [excluding natural gas] (log)	-.136**	-.00257
	(.0586)	(.00239)
Total energy use (log)	-.0166	-.000625
	(.0126)	(.000571)
Tons of carbon emissions from fossil fuel use (log)	-.0436	-.00280**
	(.0289)	(.00123)
Employment (log)	.00417	.000395
	(.00881)	(.000267)

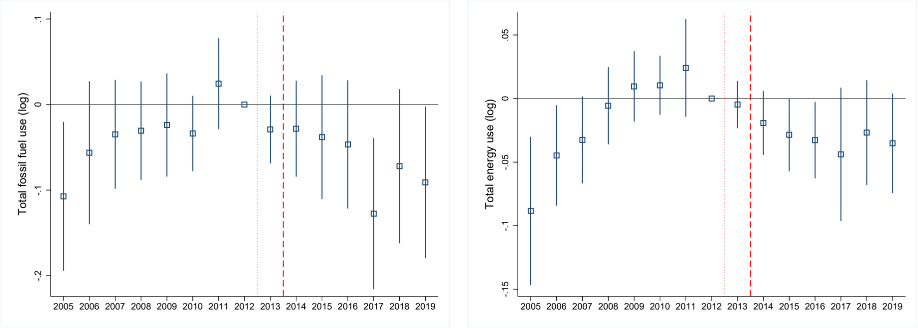
Note: Average effects are estimated based on Equation (5). The ratio over fossil fuel use (%) represents the percentage share of electricity over the sum of electricity and fossil fuel use. Electricity and fossil fuel represents 96% of total energy use, on average. The carbon intensity of fossil fuel use and the carbon intensity of total energy use represent the ratio of tons of carbon emissions from fossil fuel use over total fossil fuels and energy use, respectively. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Employment refers to average employment as at the end of the year as reported by the plant in the Eacei datasets. Standard errors are in parenthesis. Statistical significance is marked with *(0.1 $>$ p-value$>$ 0.05), **(0.05 $>$ p-value $>$ 0.01), ***(p-value $<$ 0.01).

Figure B11: Dynamic DiD effects of exposure to carbon pricing on energy use and job outcomes (alternative exposure)



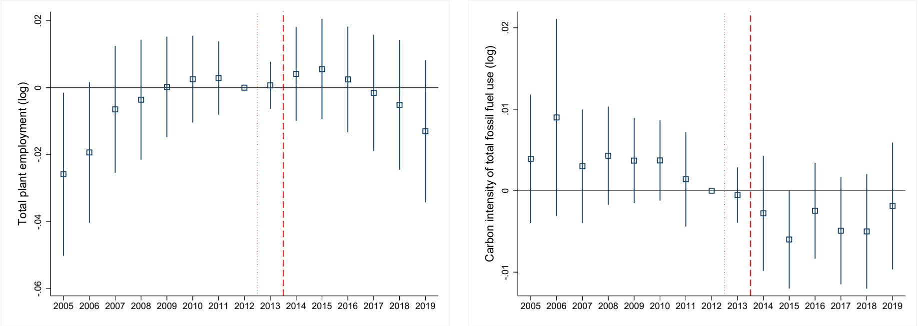
(a) Electricity over fossil fuel use (log)

(b) Total electricity use (log)



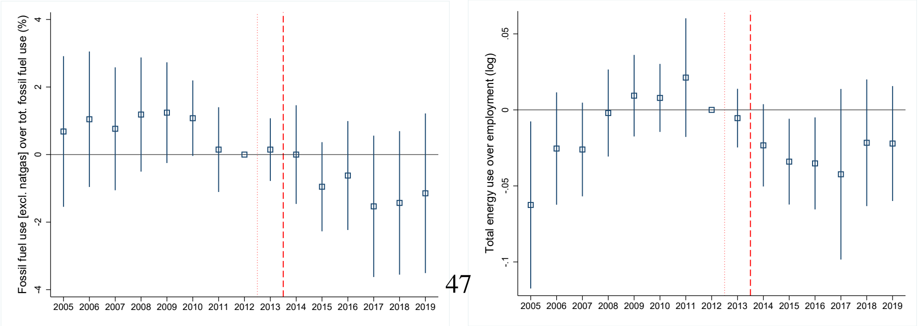
(c) Total fossil fuel use (log)

(d) Total energy use (log)



(e) Employment (log)

(f) Carbon intensity of fossil fuel use (log)

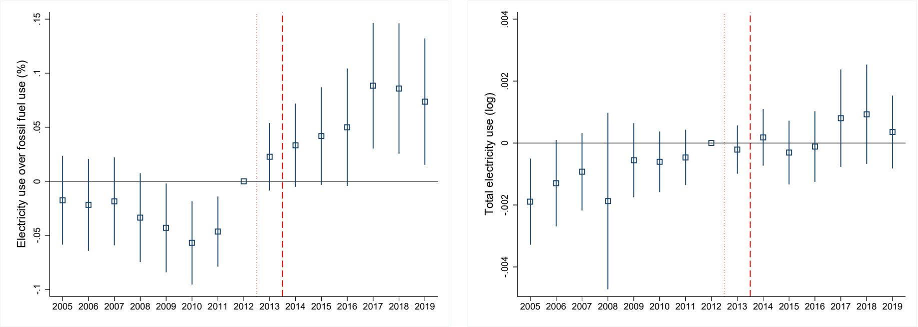


(g) Fossil fuel [excl. natgas] over tot. fossil fuels (%)

(h) Total energy use over employment (log)

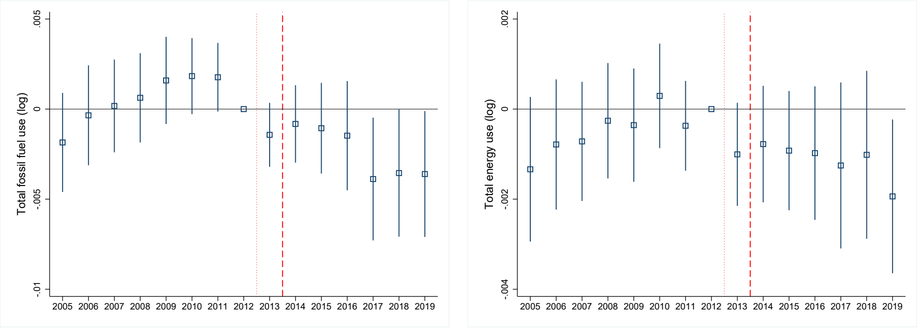
Note: Figure (B11) presents dynamic DiD results from Equation (4). The exposure variable is Equation (6). The carbon intensity of fossil fuel use and the carbon intensity of total energy use represent the ratio of tons of carbon emissions from fossil fuel use over total fossil fuels and energy use, respectively. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Employment refers to average employment as at the end of the year as reported by the plant in the Eacei datasets. The panel includes 907 plants per year. The reference year is 2012. Standard errors are clustered at the plant-level. Confidence intervals are set at the 5% level of significance.

Figure B12: Dynamic DiD effects of exposure to carbon pricing on energy use and job outcomes (including EU-ETS plants)



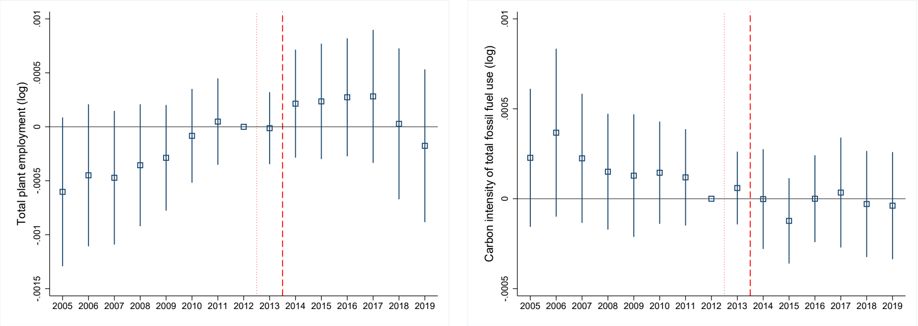
(a) Electricity over fossil fuel use (log)

(b) Total electricity use (log)



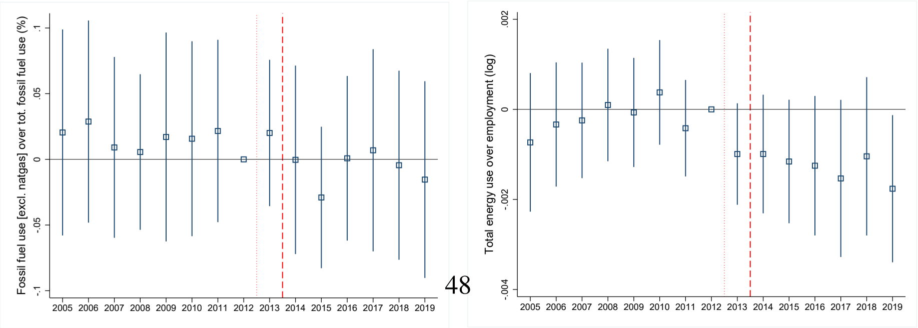
(c) Total fossil fuel use (log)

(d) Total energy use (log)



(e) Employment (log)

(f) Carbon intensity of fossil fuel use (log)



(g) Fossil fuel [excl. natgas] over tot. fossil fuels (%)

(h) Total energy use over employment (log)

Note: Figure (B12) presents dynamic DiD results from Equation (4). The exposure variable is Equation (1). The sample includes plants that participate in the EU-ETS, amounting to 1 185 plants per year. The carbon intensity of fossil fuel use and the carbon intensity of total energy use represent the ratio of tons of carbon emissions from fossil fuel use over total fossil fuels and energy use, respectively. Fossil fuels include natural gas, other gases, coal, lignite, coal coke, petroleum coke, butane propane, heavy fuel and domestic fuel. Employment refers to average employment as at the end of the year as reported by the plant in the Eacei datasets. The panel includes 907 plants per year. The reference year is 2012. Standard errors are clustered at the plant-level. Confidence intervals are set at the 5% level of significance.