The effects of energy price and carbon taxation on the French manufacturing sector

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Very preliminary, please do not circulate.

Abstract

This paper investigates the link between exogenous energy price changes and firm-level environmental and economic performance. Using a unique dataset containing firm-level data from the French manufacturing sector, we find that a 10% increase in energy price reduces energy use by 6% and CO_2 emission by 8%. We also find that the same increase in the energy price reduces employment by 2% and real output by 4% of firms operating in energy intensive industries but has no effect on the competitiveness of firms in non intensive industries. We find some evidence that in the short-run firms clean-up through the substitution of energy for labor and capital but not through the adoption of energy saving technologies. In addition, we explore the drivers of the manufacturing-wide energy intensity. We find that (i) aggregate energy intensity of the French manufacturing sector has decreased by 60% between 2001 and 2013, (ii) the changes in manufacturing-wide energy intensity is driven by the entry of more energy efficient firms and the exit of more energy intensive firms, (iii) a large part of entry is explained by the increase in the energy price. The policy implications of this paper are illustrated with a simulation of the effect of the French carbon tax on CO_2 emissions and employment.

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1 Introduction

Reducing energy consumption could bring in numerous private and social benefits, which can come in the form of lower energy bills or reduced carbon emissions associated with energy use. It is for this reason that many governments around the world have adopted policies to reduce energy consumption. The EU, for example, has set itself a 30% energy savings target by 2030 and proposed policies to ensure that the target is met. In France, having to address climate change concerns as a top priority, "[it] has developed an ambitious and integrated energy and climate policy framework for the energy transition towards 2030 and has adopted significant new policies, including carbon budget/pricing instruments, tax incentives and considerable public funding towards implementing it" (International Energy Agency, 2017).

Among the policies aimed to reduce energy consumption, price-based interventions, such as emission tax or cap-and-trade, provide an appealing solution simply because changes in energy price provide direct incentives to consumers to reduce their energy consumption (Jacobsen, 2015). This is in contrast to imposing standards that are viewed to be associated with higher pollution abatement costs (Holland, 2012) or unnecessary infringement of consumer choice (Gayer and Viscusi, 2013), which may negatively impact consumer welfare. However, these price-based policies impose a cost on the consumers through increases in the effective energy price.[1] Moreover, some of these policies are implemented simultaneously or layered on top of the other, leading some consumers, mostly businesses, to pay emission taxes several times over (Bassi et al., 2013).

The manner by which businesses respond to the climate change policies can therefore be approximated by how they react to changes in energy prices. Thus, results from any analysis looking at business responses to energy price changes has huge policy implications. For example, the economic losses among affected businesses may be small or even negative if the price change prompts companies to invest in unexploited high return energy efficient technologies. In contrast, the economic losses may be significantly greater if they respond by reducing their consumption of energy services and eventually output and employment. It is for this reason that evidence exploiting firm-level responses to increased cost of energy is needed to enhance our understanding of the ultimate economic consequences of these climate change policies. Evaluating the impact of the carbon tax is particularly important in France where 80% of the carbon tax revenue, 3.8 billion euros in 2016, is used to finance the tax credit for competitiveness and employment (CICE), an important policy instrument used by the French government since 2013 to encourage job creation.[2]

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[1] There some policies that are levied at the point of energy generation (e.g., EU emission trading system or the EU-ETS for power generators), but the cost is passed-through to downstream energy users in the form of higher energy prices (Sijm et al., 2008; Lise et al., 2010; Alexeeva-Talebi, 2011).

[2] Data are from the French Ministry of ecology. Every French firm is eligible to the CICE, a tax credit equal to 6% of the firm's total payroll under 2.5 times the minimum salary.

This paper contributes to the policy debate by performing two analyses utilizing a unique dataset that combines firm-level information from the French Statistical Office (Insee). These information include the energy consumption and expenditure from the survey EACEI (Enquête sur les consommations d'énergie dans l'industrie), financial data from FARES (Fichier complet unifé de SUSE) and FICUS (Fichier approché des résultats Ésane), innovation data from the Community Innovation Survey (CIS), and investment data from the Quarterly Investment Survey.

First, we examine the drivers of the energy intensity of the entire French manufacturing sector. Following Brucal et al. (2018), we decompose the manufacturing-wide energy intensity into two components: (i) a firm-level component reflecting firm adjustment and (ii) a between-firm component reflecting output reallocation of production between firms. This allows to measure the relative importance of the two channels. Then, we estimate the effect of fixed-weight energy price index on the manufacturing-wide energy intensity and its two components. This provides some indication on the contribution of the energy price to the change in the aggregate energy intensity. We find that (i) aggregate energy intensity of the French manufacturing sector has decreased by 60% between 2001 and 2013, (ii) the changes in manufacturing-wide energy intensity is driven by firm-level reduction, (iii) a large part of this firm-level reduction is explained by the increase in the energy price that facilitates the entry of more efficient firms on the market.

Second, we estimate the responses of French manufacturing firms to exogenous changes in energy prices at the micro-level. Our identification relies heavily on the use of the fixed-weight energy price index as an instrumental variable for average enery cost, following Linn (2008) and Sato et al. (2015). We argue that assessing energy use using average energy cost directly would result in biased estimate due to potential endogeneity issues associated with factors that can affect energy demand and prices simultaneously. The index uses industry-wide average prices of different fuels and electricity and, by construction, does not include the effects of technological change, substitution or industry-specific shocks on output demand (Linn, 2008).

Our micro-level results suggest that increases in energy prices result in a decline in energy use, with the own-price elasticity equivalent to 0.9. This figure is higher than estimates from previous studies looking at short-run responses of industrial energy users to energy price changes (see Labandeira et al. (2017) for a comprehensive review). French firms are more sensitive to natural gas prices than to electricity rates. We also find that, in energy intensive industries, output and employment decline as energy price increases, which suggests that environmental goals have real economic consequences. However, we argue that the employment and output elasticities (0.2 and 0.4, respectively) are far smaller than that of own-price elasticity, suggesting that affected firms manage to reduce their energy intensity. We find that only firms in non energy intensive industries decrease their energy intensity in response to short-run energy price increase. These firms clean-up by substituting energy for labor and capital but not through the adoption of energy saving technologies.[3] Finally, we find that only large firms reduce employment in response to higher energy price. This is important considering that 90% of French industrial firms are Small and Medium size Enterprises (SMEs).

Lastly, we illustrate the policy implications of this paper with a simulation of the effect of the French carbon tax on CO_2 emissions and employment for 25 industries. We examine an increase of the carbon tax on natural gas consumption from 5.6 to 10 € per MWh leads an average French firm to reduce its CO_2 emissions by 400 tons and its employment by 2.[4] Assuming our sample of firms is representative of the French manufacturing sector, we find that the carbon tax increase reduce total emissions by 14% and the workforce by 0.5%. These figures suggest that the French carbon policy can reduce emissions substantially and that the impact on employment is small but not negligible.

Our study is related to the literature that looks at the relationship between energy prices and energy use. As early as in 1951, studies of energy consumption across time has began, following the works of Houthakker (1951) who looked at energy consumption in Great Britain. Thereafter, several papers have followed, producing a wide range of estimates of own-price elasticities of energy demand (see for example, Taylor (1975); Bohi and Zimmerman (1984); Al-Sahlawi (1989) for a survey on select energy inputs).[5] There were also attempts to summarize these elasticity estimates in a single-value using meta-analysis, although most of these attempts focus on gasoline (see, for example, Espey (1996); Brons et al. (2008); Havranek et al. (2012); Labandeira et al. (2017)). As a very general finding, the empirical literature has identified non-negligible fuel and electricity elasticities, especially in the long run. Nonetheless, none of the above studies have gone to further characterizing the manner by which consumers reduce their energy consumption.

Our study is also related to broad literature that examines the substitutability between energy and non-energy inputs. The literature began from the seminal paper of Berndt and Wood (1975) who found substantial complementarity between capital and energy inputs in the US economy. Thereafter, a large number of empirical papers emerged, but only relatively more recent studies employ microlevel data. Pioneering works that use micro-level data include Woodland (1993) on US firms who found substitutability between energy and capital. In constrast, Arnberg and Bjørner (2007), using a Danish micropanel, find complementarity between electricity and capital and capital and other energy fuels and substitutability between energy and other production factors. We contribute to this literature by providing new evidence based on exogenous price changes as opposed to average sectoral or national price indices that are potentially subject to aggregation bias and

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[3] It is also possible that firms clean up by reallocating production between its plants but that is something we cannot test or measure with our data.

[4] 5.6 € per MWh corresponds to the 2017 rate while 10 € per MWh is the rate that will be in force in 2019.

[5] For an illustration of the variability of these elasticity estimates across energy inputs, see the review of Labandeira et al. (2017).

other endogeneity issues.

In addition, this paper relates to studies looking at the effect of the energy price on the discrete adoption of energy efficient technologies by manufacturing firms. Pizer et al. (2001) employs a cross-section of 3,000 US plants and finds very little evidence that variation in the energy price lead to more energy efficient technology adoption. Using a micropanel of 9,000 US firms, Anderson and Newell (2004) find that a 10% increase in energy prices increases the probability of adoption by 0.4% conditional on the anticipated quantity of energy saved by the technology. We contribute to this literature by estimating the effect of the energy price on several types of innovations including energy saving innovation.

More generally, the study is related to the growing literature evaluating environmental policies on firm-level environmetal performance. For the US, Walker (2013) and Greenstone et al. (2012) find negative effects of changing environmental regulation on workers earnings and productivity, respectively. In contrast, Martin et al. (2014) estimated the effect of imposing carbon tax on UK manufacturing plants from 1999 up to 2004. The carbon tax, which is equivalent to a 10% increase in electricity prices, significantly decreases plant-level energy use by 20% while not affecting employment. Flues and Lutz (2015), using data on German manufacturing firms for the period 1995-2005, find no significant effect of increasing the marginal tax rate on electricity on turnover, export, or employment. Similarly, Gerster (2015), using the same data but for the period of 2008-2011, finds no significant effect on the same economic variables, but the lowered marginal tax rate increased electricity use by 30%.

Meanwhile, Wagner et al. (2014) find that EU-ETS regulated plants reduced both emissions and employment, although the reduction in emissions outweigh that of employment significantly. Using a micro dataset of German firms, Pertrick and Wagner (2018) find that regulated firms abated one fifth of their CO_2 emissions between 2007 and 2010, but find no evidence that emissions trading lowered employment, gross output or exports of treated firms. In general, firms responds to environmental policies by cutting down on the regulated energy inputs. However, the results in terms of the trade-off between environmental goals and economic outcomes remain mixed.

Our paper is similar to Marin and Vona (2017) who analyzed the impact of energy prices on employment and environmental performance of French manufacturing plants. Their results highlight a trade-off between environmental and economic goals: although a 10 percent increase in energy prices brings about a 6 percent reduction in energy consumption and to a 11 percent reduction in CO_2 emissions, such an increase also has a modestly negative impact on employment (-2.6 percent) and very small impact on wages and productivity. Our study is different in several respects. First, while Marin and Vona (2017) focus on surviving plants response to energy price variation, we start by examining the evolution and the components of the manufacturing-wide energy intensity and stress the importance of firms' entry and exit. Second, we take firm as our unit of observation instead of plant. This allows to distinguish the effect of the price on real output, profitability and employment and explore the heterogeneity between SMEs and large firms.[6] Third, in addition to measuring energy use and competitiveness elasticities, we characterize the manner by which firms reduce energy use per unit of output by examining fuel choice, input substitution as well as the adoption of energy saving technologies. Fourth, we limit sample selection when testing for heterogeneous effects of the energy price on several dimensions: energy intensity, trade exposure, and firms size. Finally, we simulate the effects of a planned increased of the French carbon tax on natural gas consumption on the employment and CO_2 emissions of 25 industries.[7] We believe our paper will inform policymakers further in designing appropriate environmental measures with the least potential economic losses.

The paper is organized as follows. Section 2 briefly discusses our unique dataset. Section 3 presents the analysis of the manufacturing-wide energy intensity. Section 4 contains the empirical analysis of the effects of energy price on surviving firms' environmental performance, economic performance, input substitution, and energy saving technology adoption. Section 5 shows the effect of a planned carbon tax increase on firm CO_2 emissions and employment. Finally, Section 6 concludes the study.

2 Data

2.1 Source and definition

Our main dataset consists in an unbalanced panel of 4,800 French firms observed yearly from 2001 to 2013 covering the entire manufacturing sector with the exception of the industries of tobacco, arms, and ammunition. We obtain this dataset by merging 2 datasets: a energy use dataset and a fiscal dataset described below.

Fuel consumption and expenditure data come from the EACEI survey conducted by Insee. The EACEI survey provides for electricity, natural gas, coal, oil, and other fuels. We combine CO_2 emission factor from the French Environment and Energy Management Agency (Ademe) with fuel use to compute CO_2 emissions from fuel combustion. These energy data are available at the plant level. However, our level of analysis is the firm since most data are available at the firm level and not at the plant level. Therefore, we aggregate the energy data from the plant level to the firm level. This aggregation is straightforward for single-plant firms. To obtain multiple-plants firms, we need the data for all plants. To verify whether this is the case, we proceed as follows. First,

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[6] We also measure investment response and use more recent data than Marin and Vona (2017) who cover 1997-2010.

[7] Marin and Vona (2017) perform a simulation of a 56 € / t carbon tax but do not provide the magnitude by industry.

we compute the sum of employees for the plants for which the energy data is available using the stock of establishment provided by Insee. Second, we compare the sum of the plants to the total number of employees of the firms. If we cover at least 85% of the firm's total number of employees, we consider that the sum of energy expenditure and use of its plant is a measure of the firm's total energy expenditure and use.

Data on turnover, number of employees, and total investment come from the census provided by the French Ministry of Finance at the firm level. We deflate output using 3-digits industry producer price indices provided by Insee.

In this paper, we also test the effect of the energy price on innovation. Firm-level data on innovation come the Community Innovation Survey (CIS). The CIS ask firms if they introduced new processes or new products. In addition, the CIS asks how important were firms' innovation in terms of reduction of material and energy use per unit of output. Firms have four exclusive choices: 'not relevant', 'low importance', 'medium importance', and 'high importance'. We translate the answer into a energy saving innovation dummy variable equal to 1 when firms answer medium or high important and zero otherwise. However, data availability for our innovation measures is much lower than the availability of the energy use data. Therefore, we to build an additional smaller dataset to maximize the number of observations.

2.2 Stylized facts

Figure 2 shows the average energy intensity by 2-digits manufacturing industry.[8] The ranking of the industries are consistent with expectations. The least energy intensive industries include leather, computer, electrical and machinery while the most energy intensive industries include non metallic minerals, chemical, basic metals, and paper. Figure 3 plots energy intensity as function of the average energy cost. The figure shows that the most energy intensive industries face the lowest energy prices. This is consistent with the fact that large consumers of energy receive quantity discount. Figure 1 shows the evolution of the average energy cost between our observation period. On average, the energy cost increased from 450 € per toe in 2001 to 700 € per toe in 2012. This overall increase is consistent with the trend of the West Texas Intermediate crude oil price.

We observe significant variation of the energy cost across industries in Figure 2 and significant variation of the average energy cost over time in Figure 1. However, for identification we need within-firm level variation of both the average energy cost and the energy price index over time. To verify whether this is the case, we scale the two variables by subtracting their within firm average. We then compute the standard variation of the two mean reduced variables. We find that the

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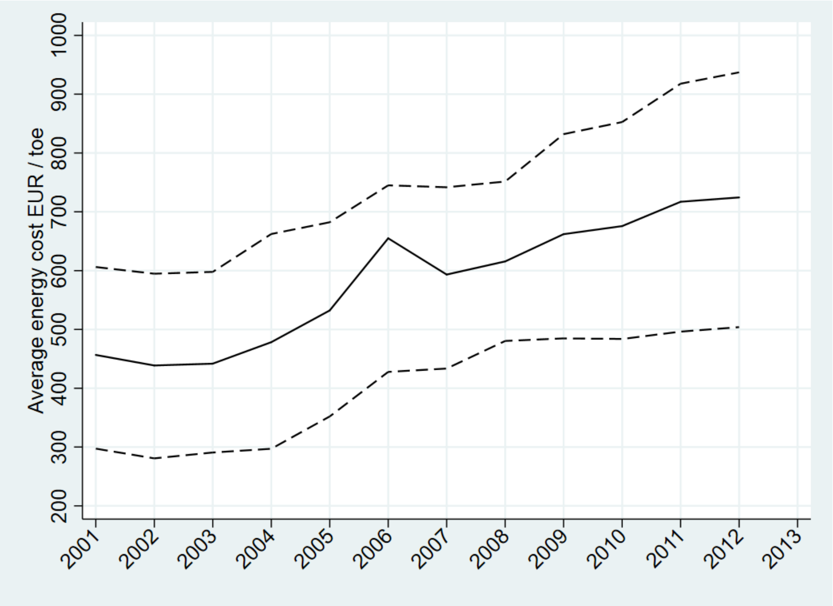
[8] Average are computed over 2003-2013.

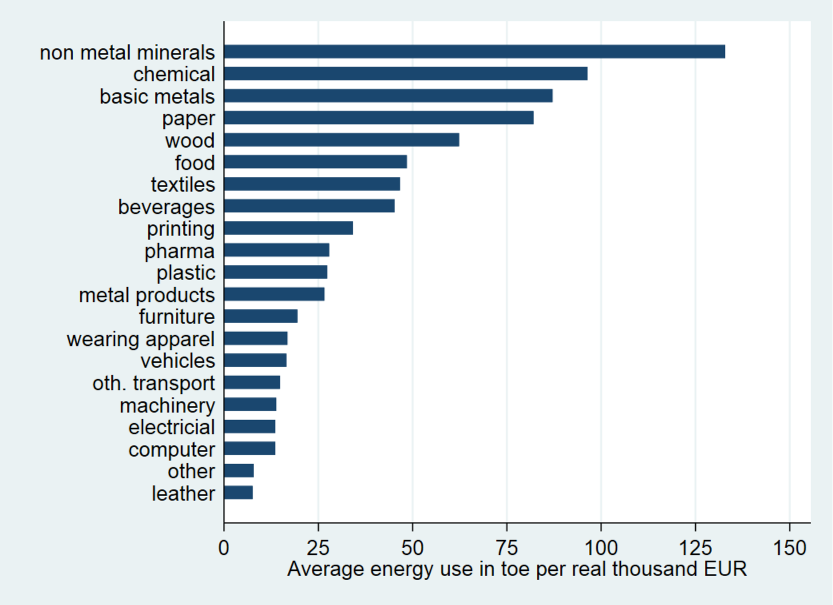
standard variation equals 17% for the average energy cost and 15% for the energy price index. Therefore, we should have sufficient within-firm level variation to estimate our models.

Figure 1: Evolution of the average energy cost



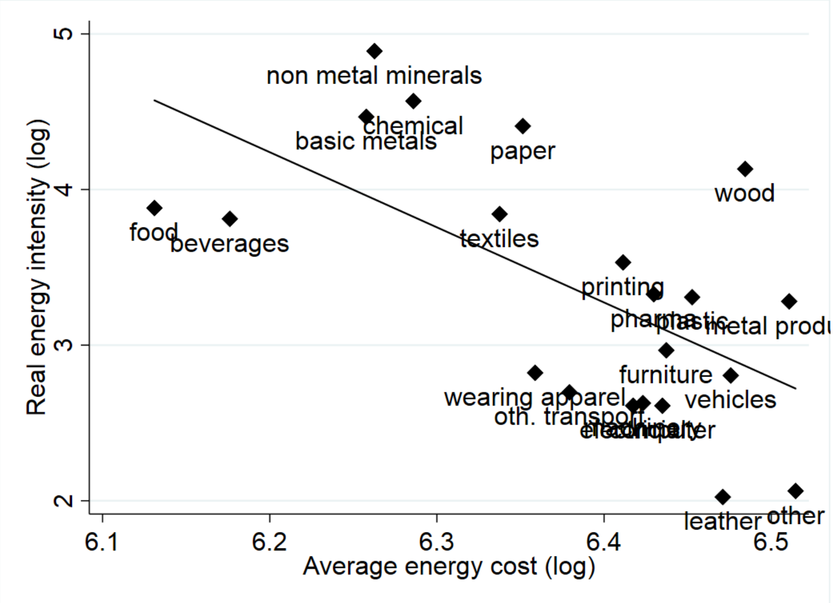
Dotted lines represents the 10th and the 90th percentiles.
Source: Authors' calculation.

Figure 2: Energy intensity by industry



Average computed over 2003-2013. Source: Authors' calculation.

Figure 3: Energy intensity and average energy cost



Average computed over 2003-2013. Source: Authors' calculation.

Electricity and natural gas account respectively for 58% and 29% of total energy use for the average French manufacturing firm.[9] To preserve the number of observations in our sample and for clarity, we restrict our analysis to these two most consumed fuels in the French manufacturing sector.[10] Table 12 and 13 respectively show the summary statistics for the main dataset and the CIS dataset. 65% of the firms declare to have introduced either a new process or a new products and 40% of them have introduced an energy saving technology.

2.3 Fixed-weight Energy Price Index

In this paper, we use an exogenous measure of energy price variation. More specifically, we follow Sato et al. (2015) to compute the following fixed-weight energy price index:

$$FEPI_{it} = w_{i0}^{elec} \ln\left(p_{kt}^{elec}\right) + w_{i0}^{gas} \ln\left(p_{kt}^{gas}\right) \tag{1}$$

where w_{i0} is the electricity (natural gas) use as the share of total energy use of firm i at the pre-sample year 0 and p_{kt} is the average price of electricity (natural gas) for the 3-digits industry level k in which firm i operates at year t.[11]

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[9] In addition, for 75% of the French manufacturing firms, electricity and natural gas account for more than 80% of total energy consumption.

[10] Our results are robust to this restriction.

[11] As explained above, restricting the index to electricity and natural gas allows to save on observations without degrading the quality of the index. Linn (2008) uses a fixed-weight energy price index where the fuel weights are

The use of pre-sample weights is twofold.[12] First, it is a way to aggregate the different industry-level fuel prices into a firm-level energy price index and ensuring between firms variation. Second, firm i's decisions in the sample period are not correlated with the weights because they are fixed using data on years before the sample period. The within-firm variation thus come from the industry-level fuel prices.

The price of fuel $f = \{elec, gas\}$ in industry k at year t is computed as follows:

$$p_{kt}^{f} = \frac{\sum_{i=1}^{n_k} \left(p_{ikt}^{f} q_{ik0}^{f} \right)}{\sum_{i=1}^{n_k} q_{ik0}^{f}} \tag{2}$$

p_{kt}^{f} is the average fuel price weighted by the firms pre-sample fuel quantity purchased. Using pre-sample weights prevents p_{kt}^{f} being directly manipulated by individual firms in panel fixed-effect framework. In comparison to firm i fuel prices, the industry-level average fuel prices p_{kt} as they are assumed to be exogenous to firm i and vary across time. The validity of FEPI as instrumental variable depends on this assumption. Note that the FEPI can also be computed at the industry level.

3 What happens at the aggregate level?

3.1 Energy price and aggregate energy intensity

Before we proceed to analyzing the effect of energy price movements on firm-level environmental and economic performance, it is useful to explore first whether or not there is an indication that energy price movements influence the industry-wide environmental and economic performance. Consequently, we want to know how energy prices are associated aggregate energy intensity (measured as energy use/output) for the French manufacturing sector during our sample period. We can decompose this aggregate energy intensity into two components: the unweighted average energy intensity and covariance of energy intensity, and observe how changes in aggregate energy intensity and the two components are associated with movements in energy prices. To do this, we follow Brucal et al. (2018) and compile the aggregate energy intensity measure W_t, which is the average of the firms' individual energy intensities weighted by the firm's share in total manufacturing output s_{it}. We calculate W_t for all firms in the sample for each year t. Then we decompose the aggregate energy intensity into the unweighted aggregate energy intensity and the covariance between firm's

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computed at the level of a US state. Here total energy use is simply the sum of electricity use and natural gas use.

[12] The pre-sample year can vary across firms. Only observations for years after the pre-sample year are used in the estimation sample.

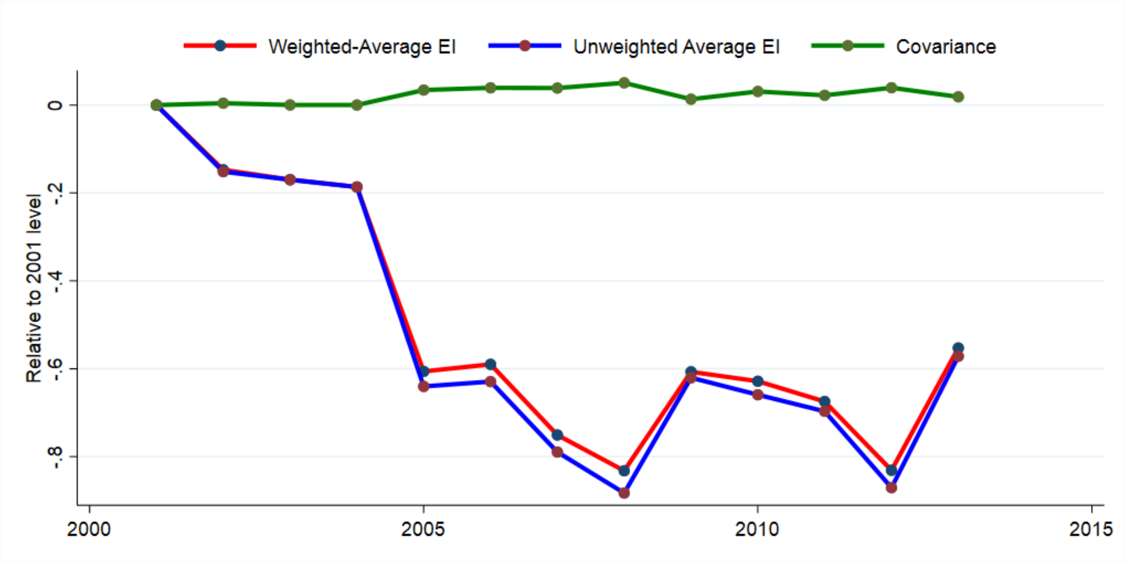
share of the entire industry's output and its energy intensity:

$$\underbrace{W_t = \sum_i s_{it}\, lnEI_{it}}_{\substack{\text{Aggregate}\\ \text{energy intensity}}} \quad = \quad \underbrace{\overline{lnEI}_t}_{\substack{\text{Unweighted average}\\ \text{energy intensity}}} \quad + \quad \underbrace{\sum_i (s_{it} - \overline{s}_t)(lnEI_{it} - \overline{lnEI}_t)}_{Covariance} \tag{3}$$

where s_{it} is the share of firm i's output to total industry's output at time t, $\overline{s}_t$ is the average share over all firms in the industry, $lnEI_{it}$ is firm i's log(energy expenditure/output), $\overline{lnEI}_t$ is the average log(energy expenditure/output) over all plants in the industry.

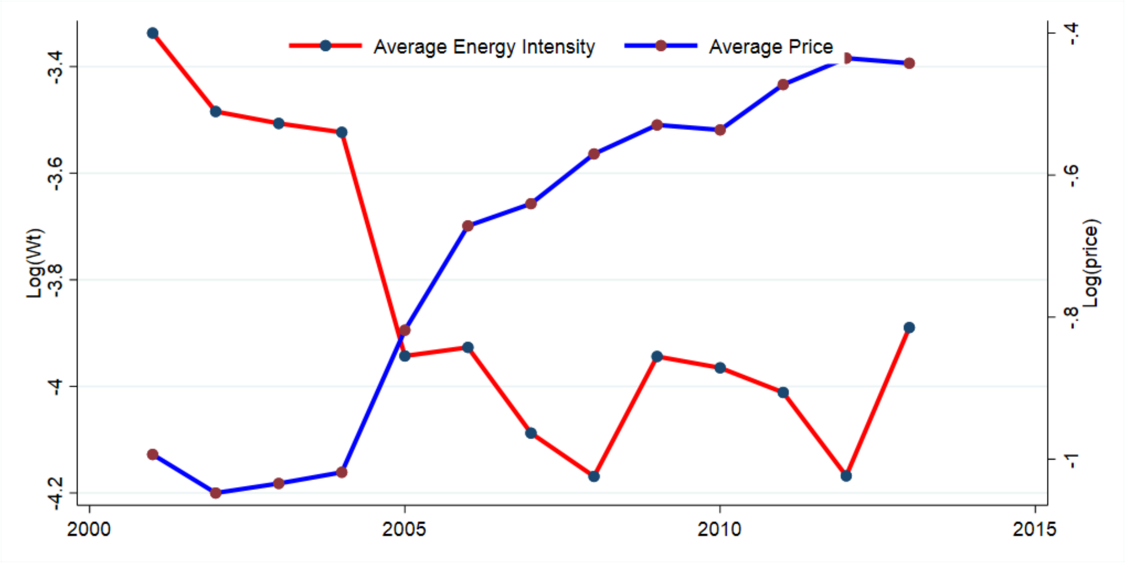
Changes in the first term (unweighted average energy intensity) reflect firm-level changes in energy intensity. Changes in the second term (covariance), if positive, indicate that more output is produced by more energy intensive producers. Thus, changes in the second term capture the effects of reallocation of market shares across firms with different energy intensity levels. Results are summarized in Figure 4. Results are expressed as changes relative to the 2001, the initial year in our sample. Our calculations show that the energy intensity of firms in our sample has continuously reduced their energy intensity up to 2008, reaching to about 90% lower compared to the 2001 level. Aggregate energy intensity increased in 2009, but then reduced again up to 2012 before increasing in 2013 to 55% relative to 2001 levels. Moreover, the changes in manufacturing-wide energy intensity seems to be driven by firm-level reduction rather than reallocation of outputs towards less energy intensive firms.

Figure 4: Aggregate energy intensity and its components in the French manufacturing industry



Note: Figures are relative to 2001 levels.
Source: Authors' calculation.

Figure 5: Aggregate energy intensity and its components in the French manufacturing industry



Note: Figures are relative to 2001 levels.
Source: Authors' calculation.

Given the observed strong downward trend in manufacturing-wide energy intensity, we then observe how energy prices are associated with changes in aggregate energy intensity. We then plot the aggregate energy intensity with our average energy price index, $FEPI_t$. We find strong negative correlation between the our price index and the aggregate energy intensity over the sample period (Figure 5). We then formally assess how changes in the energy prices are associated with industry-wide aggregate energy intensity by regressing the aggregate energy intensity and each of its components on our measure of energy prices, $FEPI_{it}$ at the 3-digit industry-year level. Thereafter, we estimate the following equation:

$$EI_{kt} = \beta FEPI_{kt-1} + \gamma_k + \delta_t + \lambda_{st} + \varepsilon_{kt} \tag{4}$$

where EI_{kt} is the aggregate energy intensity and its components relevant to industry k operating at year t and $FEPI_{kt-1}$ is the lagged fixed-weight energy price index in the 3-digit industry. γ_k, δ_t, and λ_{st} are 3-digit industry-, year- and 2-digit sector-year fixed effects, respectively. Following Brucal et al. (2018), we weight all observations using the maximum number of firms observed in each industry group during the entire sample period to ensure that industries with large firms populations receive higher weight and make the results representative. Standard errors are clustered at the sector level. To test the robustness of our results, we also perform the same regression using contemporaneous energy price index, $FEPI_{kt}$.

Results are summarized in Table 1. Our estimation shows that increased energy prices is negatively associated with aggregate energy intensity. This suggests that increased pries may be facilitating improvements in overall energy intensity in the French manufacturing industry during the sample period. We also find that an indication showing that price-induced reduction energy intensity may be channeled through within-firm reduction in energy per unit of output rather than a reallocation of market shares towards less energy intensive firms.

3.2 Energy price, firm entry and exit, and growth

It should be noted that our aggregate energy intensity and its components are all affected by changes in the energy intensity among the surviving firms, as well as by entry and exit of firms in the industry. Thus, it is also useful to see how energy prices are associated with the employment change in the sector as a result of their expansion and entry on the one hand and their contraction and exit on the other. To do this, we first define the growth rate in the size of a firm i from $t-1$ to t, following Davis and Haltiwanger (1992, 2001), as

$$g_{it} = \eta_{it} - \eta_{i,t-1}/x_{it} \tag{5}$$

Table 1: Aggregate energy intensity measures and energy price index.

	W_{kt}	$\overline{lnEI}_{kt}$	$Covariance_{kt}$
$FEPI_{kt}$	**-0.772****	**-0.754****	**-0.019**
	(0.366)	**(0.368)**	**(0.021)**
Observations	729	729	729
R-sq (adj.)	0.211	0.222	0.146
R-sq (within)	0.225	0.236	0.162
$FEPI_{kt-1}$	**-0.658****	**-0.641****	**-0.017**
	(0.313)	**(0.313)**	**(0.017)**
Observations	729	729	729
R-sq (adj.)	0.205	0.217	0.146
R-sq (within)	0.219	0.231	0.161
3-digit industry fixed-effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Note: Eech column represents separate regression runs. Standard errors clustered at the sector level are in parenthesis. *, **, *** denote significance the 10, 5, and 1 percent level, respectively.

where η_{it} represents firm i's employment at time t and $x_{it} = (\eta_{it} + \eta_{i,t-1})/2$ is the average size of the firm. This growth rate measure is symmetric about zero and lies within the interval [-2,2] with deaths and births corresponding to the left and right endpoint, respectively. By construction, this employment growth rate measure accounts for entry and expansion of firms, as well their death and shrinkage. Figure 6 plots the empirical density for the French firms' employment growth rates covering about 4,800 firms the period 2001 to 2013. Figure 6 suggests that about 15 percent of all manufacturing firms experienced a growth rate in the interval (-0.02,0.02). Births and deaths account for about 42 percent of annual growth rate observations in the sample.

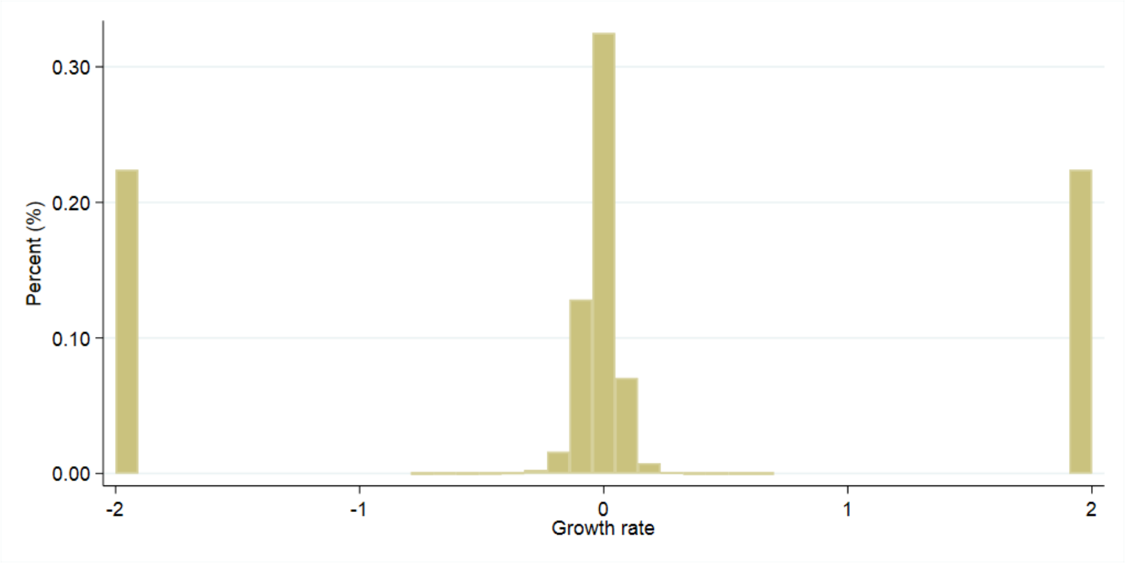
Next, we calculate gross job creation by summing employment gains from expanding and new firms in a particular county-year-cell. Similarly, we calculate gross job destruction by getting the total employment losses from shrinking and dying firms. We normalize these measures with the total employment in industry k, X_{ikt}, to express them as rates. We can then write gross job creation and destruction rates, respectively, in industry k at time t as:

$$POS_{kt} = \sum_{e \in F_{kt}} (\frac{x_{et}}{X_{kt}}) g_{et},\ \forall g_{et} > 0 \quad \text{and} \quad NEG_{kt} = \sum_{e \in F_{kt}} (\frac{x_{et}}{X_{kt}}) \mid g_{et} \mid,\ \forall g_{et} < 0 \tag{6}$$

where F_{kt} is the set of all firms in k at t. Finally, we define net job creation as $NET_{kt} = POS_{kt} - NEG_{kt}$.

We estimate equation 4 again but replacing our dependent variable with our employment change measures to see how firms' expansion and entry (as well as exit and shrinkage) influences our aggregate measures of energy intensity.

Figure 6: Employment growth rate distribuion of French manufacturing firms.



Results are presented in Table 2. We see that gross job creation, which represents firms' entry and expansion, is associated with a decline in the aggregate energy intensity. More specifically, doubling the total size of firms can reduce aggregate energy intensity by almost 17 percent. The reduction in aggregate intensity is largely driven by within-plant. Gross job destruction, which signifies firms' shrinkage and exit, is negatively associated with aggregate energy intensity. This suggests that as more firms are shrinking and exiting out of the industry, aggregate energy intensity declines. Meanwhile, net job creation, which measures the relative strength of the previous two employment change measures, is negatively associated with aggregate energy intensity but statistically insignificant.

Overall, our results suggests that the decline in aggregate energy intensity may be driven by increased entry and exit of firms in the industry. To get an insight on what might be the role of energy prices in this changes, we regress the calculated gross job creation, destruction and net creation indices against our energy price index, $FEPI_{kt}$. Results are summarized in Table 3. We find that increased energy prices are associated with an increase in the rate of gross job creation. This suggests that as energy prices increases, surviving firms tend to expand their output or new firms enter the market. We do not see very strong evidence to suggest that increased energy prices shrinks firms or drive them away out of the market. This findings are supported by the statistically positive coefficient of net job creation. We see the same trend if we used the one-year lagged energy price index, although the estimates are larger and statistically more significant.

Table 2: Regression results: Decomposition of weighted aggregate energy intensity and job creation-destruction indices

	W_{kt}	$\overline{lnEI}_{kt}$	$Covariance_{kt}$
POS_{kt}	**-0.166*****	**-0.161*****	-0.006
	(0.060)	**(0.059)**	(0.005)
Observations	729	729	729
R-sq (adj.)	0.207	0.218	0.149
R-sq (within)	0.221	0.232	0.164
NEG_{kt}	**-0.238***	**-0.247****	0.008
	(0.120)	**(0.122)**	(0.008)
Observations	729	729	729
R-sq (adj.)	0.193	0.207	0.146
R-sq (within)	0.208	0.221	0.161
NET_{kt}	-0.082	-0.076	-0.005
	(0.052)	(0.051)	(0.004)
Observations	729	729	729
R-sq (adj.)	0.191	0.203	0.150
R-sq (within)	0.205	0.218	0.165
3-digit industry fixed-effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Table 3: Regression results: Job creation-destruction indices and energy price index.

	POS_{kt}	NEG_{kt}	NET_{kt}
$FEPI_{kt}$	**0.467****	-0.075	**0.542***
	(0.228)	(0.103)	**(0.296)**
Observations	729	729	729
R-sq (adj.)	0.138	0.081	0.123
R-sq (within)	0.154	0.098	0.139
$FEPI_{kt-1}$	**0.645*****	**-0.115***	**0.760*****
	(0.196)	**(0.062)**	**(0.214)**
Observations	729	729	729
R-sq (adj.)	0.149	0.083	0.134
R-sq (within)	0.165	0.100	0.150
3-digit industry fixed-effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

4 Firm-level adjustments to energy price variation

4.1 Empirical Strategy

We estimate the short-run effect of the energy price on surviving firms environmental, economic performance, and energy saving technology adoption using the following model:

$$y_{it} = \beta_0 + \beta_1 Cost_{it-1} + \beta_2 X_{it-1} + \mu_i + \gamma_t + \epsilon_{it} \tag{7}$$

where y is an outcome variable for firm i at time t, such as energy use, the number of workers, real output, energy saving technology adoption, etc. $Cost$ is the logged average energy cost measured by the ratio between expenditure in electricity and natural gas in thousand euros and the purchased quantity of these two fuels in toe. X is a vector of firm-level controls that includes a dummy equal to 1 when the firm is under the European Union Emission Trading Scheme and the average age of the firm's plants, μ_i is unobserved heterogeneity, γ_t are year dummies, and ϵ_{it} is the error term.

We estimate equation (7) with a fixed-effects estimator that allows us to control for time invariant and firm specific characteristics μ_i that are correlated with the energy price index as well as with the outcome variables. This captures difference across firms operating in industries that vary substantially in terms of energy intensity. Large firms operating in the chemical industry obviously employ more workers, consume more energy, and face different fuel prices than small firms operating in the wearing apparel industry. Suppressing μ_i also controls for historical fuel mix, used in the computation of the energy price index, that is likely correlated with future energy consumption and competitiveness.[13]

The year dummies γ_t allow us to control for consumer demand and for fuel price fluctuation at the level of France affecting all French firms outcome as well as the fuel prices used to compute the energy price index. We also include ETS status as a control variable because firms subject to EU-ETS are CO_2 intensive and are eligible to fuel tax discounts.

In equation (7), y_{it} and $Cost_{it}$ are simultaneously determined. Firm can influence the fuel price it faces by manipulating their fuel use as well as their output level or their technologies. Therefore, regressing energy use or other firm-level outcomes on average energy cost using OLS yields a biased estimate of the fuel prices even if a fixed-effects estimator is employed. To address this simultaneity bias, we instrument the energy cost variable with an exogenous energy price index described in Section 2.3. We expect FEPI to be positively correlated with the average energy cost. We test for under-identification to check the strength of our instrument.

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[13] When the dependent variable is energy saving innovation dummy, we cannot employ a fixed-effects estimator. Instead, we include 3-digits industry dummy in the model that we estimate using a Probit estimator.

All regressors are one year lagged. This reflects the time firms need to react to new average fuel prices trend.[14] For our inference, we use robust standard errors clustered at the firm level.

It is possible that firms react to energy price increase differently depending on the industry in which they operate. Firms exposed to foreign competitions could reduce employment more than non exposed firms. Similarly, firms that are energy intensive could experience a greater decline in output. To test for heterogeneous effects of the energy price, we augment model (7) with two interaction terms: (i) an interaction between the average energy cost and a dummy variable Exp_k equal to 1 if the firms operate in an industry exposed to foreign competition and (ii) an interaction between the average energy cost and a dummy Int_k equal to 1 if the firms operate in an industry that is energy intensive. The augmented model can be written as follows:

$$y_{it} = \alpha_0 + \alpha_1 Cost_{it-1} + \alpha_2 Cost_{it-1} \times Exp_k + \alpha_3 Cost_{it-1} \times Int_k + \alpha_4 ETS_{it-1} + \mu_i + \gamma_t + u_{it} \quad (8)$$

We argue that it is important to include both interaction terms in the same model in order to not confound the effects of energy intensity and trade exposure that can be correlated. Our approach differs from Marin and Vona (2017) who estimate 4 different regressions on separate samples. In contrast, we do not introduce some sort of sample selection by estimating the model on a unique sample.

To determine if a 3-digits industry is exposed to foreign competition, we compute the following trade exposure measure:

$$TradeExp_k = \frac{\sum_t M_{kt}}{\sum_t Y_{kt}} \quad (9)$$

where M_{kt} is the total French import value of goods produced in industry k and Y_{kt} is the production value of the French industry k.[15] This measures is also called import penetration and has been used in previous works (Bloom et al., 2016). The higher it is, the more exposed is the industry to foreign competition. We divide industries in two groups based on the median value of trade exposure. [16]

To determine if a 3-digits industry is energy intensive, we compute the following:

$$EnerInt_k = \frac{\sum_t E_{kt}}{\sum_t Y_{kt}} \quad (10)$$

where E_{kt} is energy use of the French industry k at year t.[17] Industries that have energy intensity measure above the French median industry are considered energy intensive. Table 17 and 18 in the

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[14] This also allows to have the identifying assumption $E\left[FEPI_{it-1}\epsilon_{it}\right] = 0$ that is weaker than $E\left[FEPI_{it}\epsilon_{it}\right] = 0$.

[15] The trade data come from the French customs and the output data are from French fiscal authorities.

[16] Marin and Vona (2017) use another measure that is the trade-related criterion for exemption from auc- tioning of allowances in the EU ETS introduced by the European Commission.

[17] The energy data come from the EACEI survey and the output data are from French fiscal authorities.

appendix show in which categories the different industries are.

4.2 Results and discussion

4.2.1 Environmental and economic performance

Table 4 shows the estimated effects of the energy price index on firm energy performance and competitiveness. We find that an increase in the energy price index is associated with a statistically significant reduction in the energy use. In particular, a 10% in the energy price leads to a decrease of 6% of the energy use. The reduction for natural gas amounting to 10% is larger than for electricity, which is equivalent to 2.6% and statistically insignificant. Consistently, the reduction in CO_2 emissions, equal to 7.7%, is larger than the energy use reduction because the combustion of natural gas generate more CO_2 than electricity use.[18] This difference in magnitude is not due to the evolution of relative fuel prices. Real electricity prices has increased 50% more than real natural gas price over the observation period.[19] The further decrease in natural gas is probably due to electricity being less substitutable.

We also find evidence that changes in energy price affects some dimensions of firms' economic performance but not all. Table 4 shows that an increase of 10% in the energy price lowers employment by 1.7% and real output by 3.6%. These elasticities are larger but lower to the estimated elasticity for energy use.[20] Moreover, the effect of energy price on investment and profitability measured by the operating margin is not statistically different from 0.

Are these elasticities the same for all French firms or do they depend on the industry's exposure to foreign competition and energy intensity? Table 5 reports the elasticities estimates for 4 groups of industries defined by the trade exposure dummy and the energy intensity dummy.[21] We find that the effect of energy cost on energy use and CO_2 emissions is approximately the same in the 4 groups of industries.

However, the effect of energy price on competitiveness differs substantially between firms operating in energy intensive industries and firms operating in non energy intensive industries. A 10% increase in the energy cost leads to a decline of 1.6% in employment in energy intensive industries whereas the effect is not significant for non energy intensive industries. Similarly, an increase of 10% in the energy price decreases real output by 4.5% in energy intensive industries whereas output is reduced

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[18] The emission factor is 2,750 kg CO_2/toe for natural gas and 582 kg CO_2/toe for electricity.

[19] Authors' calculation based on IEA (2016).

[20] Our results for energy use and carbon emissions are similar to Marin and Vona (2017)'s. However, they find a much larger impact on employment equal to 2.6%.

[21] These elasticities are obtained by the estimation of model (8).

by 2.2% in non energy intensive industries. Exposure to foreign competition alone does not affect the energy price elasticities.

Our results differ from Marin and Vona (2017) in several aspects. They find that firms in trade intensive industries are more affected than firms in non trade intensive sectors. Second, Marin and Vona (2017) find that plants operating in energy intensive industries reduce more their energy use and emissions than plants in non intensive industries. Third, their estimates on employment in energy intensive industries is twice as large as our estimates. These differences are likely due to the fact that energy intensity and trade intensity are not jointly tested in their analysis.

4.2.2 Higher energy price leads to input substitution

In the previous section, we find that a change in the energy cost has a significant effect on energy use, CO_2 emissions, employment, and output. In this section, we test whether the energy cost has an impact on energy intensity. Then, we explore by which channels the changes in energy intensity occur. Do firms reduce their energy intensity through input substitution or through the adoption of cleaner technologies?

Table 6 shows the effect of the average energy cost on energy intensity, energy use per worker, energy use per material, and energy use per capital. The effect of energy cost on energy intensity is equal to -0.24 but not statistically significant. We find some evidence that energy is substituted for labor and capital when the energy price increases. A raise of 10% in the energy cost reduces energy use per worker by 4.3% and energy use per capital by 3%. However, we do not find evidence for substitution between energy and materials.[22] Our results suggest that on average input substitution is not large enough to change energy intensity.

However, these results may hide heterogeneous effects. Table 7 shows the results for the augmented model (8). We find that only firms operating in industries that are not energy intensive significantly reduce their energy intensity in response to energy price. A 10% increase in the energy cost leads to a decline of 4.2% in energy intensity. It is also in non intensive industries that the substitution of energy for labor and capital is the highest with 6.1% and 4.9% respectively. These results suggest that in non intensive industries input substitution play an important role in the reduction of energy intensity.

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[22] Material and energy are complement in many industrial processes.

Table 4: Energy price effect on environmental performance and competitiveness

	Environmental performance				Economic performance			
	Energy use	Electricity use	Natural gas use	CO2 emissions	Workers	Real output	Investment	Operating margin
Ln(average energy cost)	-0.598***	-0.263	-1.009***	-0.773***	-0.167**	-0.363***	0.099	-0.038
	(0.174)	(0.186)	(0.234)	(0.187)	(0.072)	(0.109)	(0.440)	(0.030)
Average plant age (decades)	-0.019**	-0.022**	-0.024**	-0.018**	-0.028***	-0.032***	0.011	-0.001
	(0.008)	(0.009)	(0.011)	(0.009)	(0.005)	(0.006)	(0.022)	(0.001)
ETS (0/1)	0.013	0.024	-0.039	0.002	0.075***	0.122***	0.083	0.002
	(0.044)	(0.040)	(0.079)	(0.056)	(0.025)	(0.045)	(0.109)	(0.008)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	18,585	18,585	18,585	18,585	18,585	18,585	15,055	18,585
Number of firms	4,861	4,861	4,861	4,861	4,861	4,861	4,532	4,861
KP LM statistic	128	128	128	128	128	128	97	128

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variable are logged. All columns are estimated with the TSLS estimator. Average energy cost equals the log of the ratio between energy expenditure and energy use. The instrumental variable for average energy cost is the Fixed Weight energy price Index. The first-stage regressions is reported in Table 14. Regressors are lagged one period. Energy use is the sum of electricity and natural gas consumption. CO_2 emissions from natural gas and electricity consumption. Table 12 shows the summary statistics for the estimation sample.

Table 5: Heterogeneous energy price effects on environmental performance and competitiveness

	Environmental performance				Economic performance			
	Energy use	Electricity use	Natural gas use	CO2 emissions	Workers	Real output	Investment	Operating margin
Neither exposed or intensive	-0.643***	-0.294	-1.120***	-0.845***	-0.03	-0.228**	0.264	-0.020
	(0.185)	(0.195)	(0.248)	(0.200)	(0.077)	(0.116)	(0.490)	(0.032)
Not exposed but intensive	-0.627***	-0.268	-1.027***	-0.805***	-0.164**	-0.452***	0.037	-0.034
	(0.171)	(0.185)	(0.228)	(0.183)	(0.075)	(0.114)	(0.428)	(0.036)
Exposed but not intensive	-0.566***	-0.266	-1.022***	-0.748***	-0.119	-0.164	0.263	-0.050
	(0.195)	(0.206)	(0.266)	(0.213)	(0.080)	(0.118)	(0.506)	(0.028)
Both exposed and intensive	-0.550***	-0.240	-0.929***	-0.709***	-0.253	-0.388***	0.036	-0.050
	(0.184)	(0.196)	(0.247)	(0.199)	(0.078)	(0.115)	(0.446)	(0.031)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	18,585	18,585	18,585	18,585	18,585	18,585	15,055	18,585
Number of firms	4,861	4,861	4,861	4,861	4,861	4,861	4,532	4,861
KP LM statistic	118	118	118	118	118	118	89	118

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variable are logged. All columns are estimated with the TSLS estimator and include the ETS dummy as control variable. Average energy cost equals the log of the ratio between energy expenditure and energy use. The instrumental variable for average energy cost is the Fixed Weight energy price Index. The first-stage regressions is reported in Table 15. Regressors are lagged one period. Control variables include average plant age and ETS status but are not reported for clarity. Energy use is the sum of electricity and natural gas consumption. CO_2 emissions from natural gas and electricity consumption. Table 12 shows the summary statistics for the estimation sample.

Table 6: Energy price on energy intensity and input substitution

	Energy use per real output	Energy use per worker	Energy use per real material	Energy use per capital
Ln(average energy cost)	-0.235	-0.431***	-0.168	-0.307
	(0.180)	(0.167)	(0.252)	(0.208)
Average plant age (decades)	0.013	0.01	0.011	0.005
	(0.009)	(0.008)	(0.011)	(0.010)
ETS (0/1)	-0.109*	-0.062	-0.124*	-0.131*
	(0.059)	(0.041)	(0.072)	(0.068)
Firm FE	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Observations	18,585	18,585	18,585	18,585
Number of firms	4,861	4,861	4,861	4,861
KP LM statistic	128	128	128	128

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variable are logged. All columns are estimated with the TSLS estimator. Average energy cost equals the log of the ratio between energy expenditure and energy use. The instrumental variable for average energy cost is the Fixed Weight energy price Index. The first-stage regressions is reported in Table 14. Regressors are lagged one period. Energy use is the sum of electricity and natural gas consumption. CO_2 emissions from natural gas and electricity consumption. Table 12 shows the summary statistics for the estimation sample.

Table 7: Heterogeneous energy price effects on energy intensity and input substitution

	Energy use per real output	Energy use per worker	Energy use per real material	Energy use per capital
Neither exposed or intensive	-0.415**	-0.613***	-0.14	-0.487**
	(0.195)	(0.178)	(0.285)	(0.226)
Not exposed but intensive	-0.175	-0.463***	-0.166	-0.306
	(0.179)	(0.164)	(0.259)	(0.201)
Exposed but not intensive	-0.402**	-0.447**	-0.160	-0.379
	(0.203)	(0.187)	(0.272)	(0.242)
Both exposed and intensive	-0.162	-0.297*	-0.186	-0.197
	(0.190)	(0.174)	(0.257)	(0.220)
Firm FE	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Observations	18,585	18,585	18,585	18,585
Number of firms	4,861	4,861	4,861	4,861
KP LM statistic	118	118	118	118

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variable are logged. All columns are estimated with the TSLS estimator and include the ETS dummy as control variable. Average energy cost equals the log of the ratio between energy expenditure and energy use. The instrumental variable for average energy cost is the Fixed Weight energy price Index. The first-stage regressions is reported in Table 15. Regressors are lagged one period. Control variables include average plant age and ETS status but are not reported for clarity. Energy use is the sum of electricity and natural gas consumption. CO_2 emissions from natural gas and electricity consumption. Table 12 shows the summary statistics for the estimation sample.

4.2.3 SMEs substitute more and large firms shrink

So far, we have seen that firms' adjustment to higher energy price depends on energy intensity. Does the effect of energy price differ between Small and Medium Enterprises (SMEs) and bigger firms? Considering that 90% of the firms in the French industry are SMEs, any difference with bigger firms have important policy implications.[23] In theory there are reasons to believe that the energy price impacts small and big firms differently. Table 16 shows that SMEs consume 36% less energy per output than large firms and that their energy cost is 12% higher.[24]. Therefore, we can expect that the same increase in energy price has larger impact on big firms. On the contrary, we could also expect large firms to have more capacities, financial or managerial, to deal with price variation than SMEs. The net effect of this two opposing forces is empirical.

We test for heterogeneity between SMEs and large firms by estimating model (7). The results are reported in Table 8. We find that the effect on energy use and CO_2 emissions is statistically the same for both types of firms. However, the responses in terms of employment, production, and energy use per worker greatly differ. We find that a 10% increase in the energy price does not affect employment in SMEs but reduces employment by 32% in bigger firms. Real output is reduced by 4.6% in large firm and by 3% in SMEs. Finally, SMEs substitute energy for labor twice as much as large firms in response to the same energy price increase. This result has important policy implications. For most firms in the French manufacturing sector, the carbon tax achieve substantial environmental gain without significant impact on employment.[25]

4.2.4 Energy price has no short-run effect on innovation

Table 9 shows the estimation of model (7) when the outcome variable is innovation. We do not find evidence that the energy price is related to any kind of innovation including new processes, new products, and energy saving innovation. We don't find any difference between SMEs and big enterprises. In addition, there is no significant heterogeneity depending on energy intensity and trade exposure.[26] In the short run, our result suggests that an increase in the energy price has no effect on the clean technology innovation of surviving firms. Does it mean that policies increasing the energy price fail to clean up the manufacturing sector? Our previous results in Table 2 and 3 show that energy price is positively correlated with the entry of new firms which is itself negatively correlated with manufacturing wide energy intensity. Therefore, clean technology adoption seems

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[23] In our sample, 82% of the firms are SMEs. The EU commission and the French administration define SMEs as firms having a staff head-count lower than 250.

[24] This observation is consistent with the quantity discount.

[25] Our result is not sensitive to the threshold of 250 employees. When interacting the average energy cost and the pre-sample size, we find that the energy price has a non linear effect on employment, output, and energy use per employee.

[26] These results are not reported for clarity but available upon request.

Table 8: SMEs versus big enterprises

	SMEs		Big enterprises	
Energy use	-0.589***	(0.188)	-0.612***	(0.159)
Electricity use	-0.225	(0.199)	-0.325*	(0.173)
Natural gas use	-1.054***	(0.254)	-0.934***	(0.213)
CO2 emissions	-0.784***	(0.203)	-0.756***	(0.171)
Workers	-0.077	(0.078)	-0.316***	(0.072)
Real output	-0.303**	(0.120)	-0.463***	(0.103)
Investment	0.289	(0.480)	-0.225	(0.397)
Operating margin	-0.039	(0.031)	-0.035	(0.029)
Real energy intensity	-0.286	(0.196)	-0.149	(0.163)
Energy use per worker	-0.512***	(0.180)	-0.269***	(0.150)
Energy use per real material	-0.196	(0.272)	-0.121	(0.233)
Energy use per capital	-0.394*	(0.222)	-0.163	(0.194)
Firm FE	yes			
Year dummies	yes			
Observations	18,585			
Number of firms	4,861			
KP LM statistic	124			

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Only the average energy cost coefficient is reported for clarity. The columns and rows are separate regressions all estimated via TSLS. The instrumental variable for average energy cost is the Fixed Weight energy price Index. The first-stage regressions are available upon request. Regressors are lagged one period and include the ETS dummy and average age of the firm's plants.

to essentially occur through the entry of new firms on the market.[27] Looking back at our results in Section 4.2.2, we conclude that in the short run surviving firms reduce their energy intensity mainly through input substitution.

Table 9: **Energy price and innovation**

	Innovation introduced (0/1)	New process (0/1)	New product (0/1)	Energy saving (0/1)
Ln(average energy cost)	0.031	0.113	-0.011	-0.133
	(0.129)	(0.125)	(0.128)	(0.131)
ETS (0/1)	0.043	0.057	0.007	0.156
	(0.119)	(0.109)	(0.112)	(0.109)
Average plant age (decades)	0.002	-0.001	0.004	0.000
	(0.007)	(0.006)	(0.007)	(0.006)
Ln(employees) pre-sample	0.150***	0.174***	0.158***	0.170***
	(0.036)	(0.034)	(0.035)	(0.035)
SME (0/1)	-0.023	-0.002	0.023	0.058
	(0.059)	(0.055)	(0.057)	(0.056)
Ln(assets) pre-sample	0.145***	0.092***	0.161***	0.130***
	(0.023)	(0.022)	(0.023)	(0.023)
3-digits industry dummies	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Observations	6,613	6,613	6,613	6,613
Number of firms	3,943	3,943	3,943	3,943
KP LM statistic	641	641	641	641

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Average energy cost equals the log of the ratio between energy expenditure and energy use. All columns are estimated via IV-Probit. The instrumental variable for average energy cost is the Fixed Weight energy price Index. The first-stage regressions are available upon request. Regressors are note lagged in the IV-Probit estimations to prevent the loss of too many observations. Table 13 shows the summary statistics for the estimation sample.

4.2.5 Testing for weak instrument

The consistency of these estimations lies on the strength of our instrumental variable. The estimated Kleibergeen Paap statistic is statistically different from zero in all regressions.[28] Thus, we reject the null hypothesis that FEPI is a weak instrumental variable. Table 14 shows the first-stage estimation results. The coefficient of FEPI equals 0.256 and is statistically different from 0 at the 1% level. In addition, the F-statistic equals 539 which is way above 10 that is the usual threshold used.[29]

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[27] This is consistent with the negative impact of the average age of the plants on energy use and carbon emissions in Table 4.

[28] The Kleibergeen Paap statistic is a version of the first(stage F-statistic that is robust to heteroskedasticity.

[29] First-stage results for the estimation of the augmented model are available upon request.

5 Quantifying the effects of a carbon tax increase

In this section, we simulate the impact of carbon tax increased on firms CO2 emissions and employment. The carbon tax has been introduced in France in 2014 at 7 € per ton of CO2. Table 10 shows the evolution of the legislation. Since its introduction, the carbon tax has dramatically increased to reach 30.5 € per ton of CO2 in 2017. Because fuel have a different emission factor, the tax on CO2 translates into different fuel specific carbon taxes. In this section, we will focus on the carbon tax on natural gas (TICGN). [30]

Table 10: The evolution of the French carbon tax

	Carbon tax (€ / ton of CO2)	Natural gas (€ / MWh)	Coal (€ / MWh)
2014	7.0	1.41	2.29
2015	14.5	2.93	4.75
2016	22.0	4.34	7.21
2017	30.5	5.88	9.99
2018	44.6	8.45	14.62
2019	55	10.34	18.02
2020	65.4	12.24	21.43
2021	75.8	14.13	24.84
2022	86.2	16.02	28.25

Source: The data for the years before 2018 come from article 266 quinquies B of the French customs law. The data from 2018 comes from the first part of the 2018 Finance Bill adopted by the French Parliament on October 24th 2017.

We consider a scenario where the carbon tax on natural gas increases from its 2017 rate of 5.88 € per MWh to 10 € per MWh. First, we use firm-level data of 2013 to compute the change in average energy cost due to the tax increase.[31] Second, we map the average energy cost change into emissions reduction and employment reduction using our elasticities estimates reported in Table 8.[32] We use the model with the SME interaction because it explains more variation than the model with energy intensity and trade exposure interactions.

Table 11 shows the results for 24 different industries. Under the 10 € per MWh scenario, the average energy cost rises by 4% on average. There is substantial heterogeneity across industries that is consistent with the difference in natural gas intensity between the industries. The increase in energy cost is up to 7% for terracotta products, pulp, and basic chemicals whereas it is not above 2% for electronic components, plastics, wires and cables. The average firm reduces its emissions by 371 tons of CO_2 and its employment by 2. The largest emissions declines are over 1 kilotons of CO_2

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[30] As explained in Section 4.1, electricity and natural gas account respectively for 58% and 29% of total energy use for the average French manufacturing firms.

[31] As in our estimation, the average energy cost is measured with electricity and natural gas price and consumption.

[32] The coefficients used for a firm thus depends on whetehr the firm is a SME or not.

and take place for basic steel, terracotta products, pulp, and basic chemicals. The largest loss in employment, around 6, occurs for basic steel, terracotta products, and wires and cable. However, the reduction in employment is lower than 2 for half the industries. Note that these industry specific simple averages are driven by large firms. Consequently, the averages tend to overestimate the reduction in emissions and employment.

Finally, we provide an order of magnitude of the effect at the manufacturing sector level. To do that, we need to assume that the firms in our sample are representative of their industries. We use data on the number of firms and the number of employees for the universe of French firms provided by Insee. To obtain the total reduction of emissions, we multiply the industry-specific marginal effects reported in Table 11 by the total number of firms operating in these industries.[33] To compute total employment loss, we only consider firms that are not SMEs as the effect of energy price is not statistically different from zero for SMEs. For each industry, we compute the average percentage of employment loss using the energy cost increase on the 2013 data and the employment elasticity of Table 8. For all non SMEs, we multiply the industry specific percentage loss with the firm actual number of employees. These firm level losses are then summed to estimate the total loss in the 24 industries.

We find that increasing the carbon tax on natural gas from 5.88 € per MWh to 10 € per MWh reduces CO_2 emissions by 8 million tons and employment by 5.2 thousand representing respectively 14% of total emissions and 0.5% of the workforce. Not that these figures are only orders of magnitude and not accurate estimates.[34].

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[33] The number of firms and the number of employees of all French firms are provided by Insee.

[34] We only have data for 781 of the 993 thousand firms operating in 2013 in the 24 industries

Table 11: Carbon tax increase on emissions and employment

Industry code	Industry	Firms in the sample	Share of SMEs (%)	% change in average energy cost	Reduction in emissions (tons)	Reduction in employment
162	Wood products	22	86	2.6	300	0.6
171	Pulp	19	68	6.6	1313	2.1
172	Paper products	87	84	3.7	328	1.5
201	Basic chemicals	56	82	6	1482	1.7
203	Chemicals for construction	10	80	3.1	65	1.4
204	Cleaning products	30	63	3.9	92	2.4
205	Other chemicals	23	91	4.8	120	1.9
222	Plastics	80	73	1.9	41	1
231	Glass products	45	82	5	458	1.3
233	Terracotta products	25	80	4.6	1586	5.3
239	Non metallic minerals	13	69	5.8	134	1.9
241	Basic steel	16	25	4.4	1736	7.3
242	Steel products	12	42	4.3	310	3.5
244	Non ferrous metals	34	74	4.4	497	3.3
245	Foundry	40	68	3.6	87	1.5
255	Wrought and stamped metals	40	78	3.1	200	3.2
256	Treatment of metals	46	89	2.7	85	0.5
257	Cutlery, tools and hardware	11	45	3.1	16	1.9
259	Other articles of metal	44	57	4.1	130	2.9
261	Electronic components	10	30	1.6	35	2.7
273	Wires and cables	11	36	1.9	62	6.2
274	Electric lighting fixtures	10	80	3.7	26	1.5
282	Other machinery	26	54	3.5	37	2.8
293	Automotive equipment	71	41	2.3	48	3.4
	Manufacturing weighted average	781	70	3.7	371	2.3

The quantities reported in this table are estimated using the coefficients reported in Table 8 and firms specific simulated increase in average energy cost due to the carbon tax increase in 2013. In this scenario, the carbon tax on natural gas increase from the initial value of 5.88 € per MWh to 10 € per MWh. The carbon tax on the other fuels are kept constant.

6 Conclusion

This study provides new evidence on the effect of energy price changes on firm-level environmental and economic performance using a unique dataset utilizing micro-level information from French manufacturing firms. Our study relies heavily on the variation from our fixed-weight price index, which we believe appropriately deals with the endogeneity issues inherent in using average prices.

We find aggregate energy intensity has significantly decreased between 2001 and 2013 essentially through change at the firm-level and not market share reallocation towards energy efficient firms. The decrease in overall energy intensity is consistent with the increase in the energy price during our period of observation. We also find indication that increased energy prices are associated with increasing entry of new firms and expansion of surviving firms – not be necessarily larger firms but may have more energy efficient technology and production processes, which may also be driving the decline in aggregate energy intensity over time.

In addition, our results at the micro-level highlight that while there is a trade-off between environmental and economic outcomes due to changing prices, the reduction in emission is significantly higher. Only firms operating in industries that are energy intensive experience a loss in competitiveness. In contrast with large firms, SMEs do not reduce employment in responses to higher price because they substitute energy for labor with greater magnitude. We measure the size of emission reduction and employment loss by simulating the effect of a planned increase in the French carbon tax. We find that, on average, the environmental gains are substantial compared to the employment loss.

Our approach highlights the importance of considering not only surviving firms but also entry and exit when analyzing the effects of energy price policies. Based only on surviving firms, one might wrongly concludes that higher energy price has no impact on innovation in energy saving technologies. Our analysis of firms' entry and exit supports the theory that higher energy price leads to the entry of cleaner firms.

The results of the study, while informative, warrant future research to draw more meaningful policy implications. First, because there is no output data at the plant level we do not analyze the potentially important role of between plants reallocation of production in explaining within-firm variation in energy intensity. Even if the employment effect is small at the firm-level, reallocation of production and workers between firms is not without cost or redistributive consequences. Second, our analysis on the effect of energy price on cleaner technology adoption relies on a dataset that have a limited number of firms. The discrete nature of the energy saving innovation prevents the use of a fixed-effects estimator.

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7 Appendix

Table 12: Summary statistics the main sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Energy use	18,585	6.24	1.92	-1.31	13.73
Electricity use	18,585	5.46	1.90	-2.13	11.58
Natural gas use	18,585	5.27	2.16	-3.30	13.66
CO2 emissions	18,585	13.57	2.00	5.97	21.59
Workers	18,585	4.96	1.04	2.20	10.18
Real output	18,585	10.15	1.28	6.05	15.42
Investment	15,055	6.36	1.74	-0.38	12.94
Operating margin	18,585	0.06	0.09	-0.96	0.87
Real energy intensity	18,585	-3.91	1.33	-9.83	2.17
Energy use per worker	18,585	1.28	1.43	-4.88	6.99
Energy use per real material	18,585	-2.77	1.56	-8.67	7.76
Energy use per capital	18,585	-2.82	1.30	-9.91	4.10
Number of plants	18,585	1.82	1.97	1.00	34.00
Ln(average energy cost)	18,585	-0.59	0.32	-4.23	4.94
Average plant age (decades)	18,585	2.42	2.66	0.00	11.20
ETS (0/1)	18,585	0.03	0.17	0	1
FEPI	18,585	-0.71	0.31	-2.52	0.68
SME (0/1)	18,585	0.74	0.44	0	1
Year	18,585	2007.61	3.47	2001	2013

Table 13: Summary statistics for the CIS sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Innovation introduced (0/1)	6,613	0.65	0.48	0	1
New process (0/1)	6,613	0.50	0.50	0	1
New product (0/1)	6,613	0.54	0.50	0	1
Energy saving (0/1)	6,613	0.39	0.49	0	1
ETS (0/1)	6,613	0.03	0.17	0	1
Average plant age (decades)	6,613	2.36	2.62	0	11.25
Ln(employees) pre-sample	6,613	5.06	1.30	1.61	10.26
SME (0/1)	6,613	0.62	0.49	0	1
ln(assets) pre-sample	6,613	8.89	1.81	2.40	15.97
Ln(average energy cost)	6,613	-0.54	0.35	-2.87	7.14
FEPI	6,613	-0.65	0.30	-1.63	0.10

Table 14: First-stage regressions for the model without interactions

	Average energy cost
FEPI	0.256***
	(0.028)
FEPI x Average plant age	
Average plant age (decades)	-0.003
	(0.003)
ETS (0/1)	0.117***
	(0.016)
Firm FE	yes
Year dummies	yes
Observations	18,585
Number of firms	4,861
F statistic	539

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Table 12 shows the summary statistics for the estimation sample. The average energy cost is logged.

Table 15: First-stage regressions for the model with interactions

	Log (average energy cost)	Log (average energy cost) x Energy intensive (0/1)	Log (average energy cost) x Trade exposed (0/1)
FEPI	0.250***	-0.263***	-0.408***
	(0.036)	(0.034)	(0.042)
FEPI x Energy intensive (0/1)	0.063***	0.736***	0.051***
	(0.021)	(0.016)	(0.019)
FEPI x Trade exposed (0/1)	-0.054***	-0.019	0.703***
	(0.019)	(0.016)	(0.017)
ETS (0/1)	0.107***	0.098***	0.038***
	(0.015)	(0.015)	(0.009)
Firm FE	yes	yes	yes
Year FE	yes	yes	yes
Observations	19,321	19,321	19,321
Number of firms	5,098	5,098	5,098
F statistic	526	353	190

Standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Table 12 shows the summary statistics for the estimation sample. The average energy cost is logged.

Table 16: Difference between SMEs and large firms

	SMEs	Large firms	Difference
Energy use	5.67	7.85	2.18***
Employees	4.52	6.19	1.67***
Real output	9.67	11.50	1.82***
Operating margin (%)	6.02	5.51	-0.70***
Energy intensity	-4.01	-3.64	0.36***
Energy use per employees	1.15	1.66	0.51***
Energy use per materials	-2.85	-2.53	0.32***
Energy use per capital	-2.86	-2.70	0.16***
ETS (%)	1.69	5.98	4.28***
Average energy cost	-0.56	-0.66	-0.12***

Statistics computed on the estimation sample. All variables are logged except ETS and operating margin.

Table 17: Industry classification: part 1

Code	Industry name	Trade exposure (%)	Trade exposed (0/1)	Energy intensity (toe/million €)	Energy intensive (0/1)
101	Meat	0.1	0	7.7	0
102	Fish	0.3	0	6.3	0
103	Fruits and vegetables	0.2	0	24.5	1
104	Oils and fats	0.4	0	16.0	1
105	Dairy	0.5	0	0.0	1
106	Grains	1.9	1	65.2	1
108	Other food	0.3	0	7.8	0
109	Animal food	1.0	0	12.9	0
110	Beverages	0.0	0	7.9	0
131	Textiles	0.8	0	42.0	1
132	Weaving	0.1	0	32.7	1
133	Ennoblement	0.2	0	87.7	1
139	Other textiles	2.3	1	28.6	1
141	Clothes	0.1	0	5.1	0
142	Furr products	8.6	1	0.0	1
143	Knitwear	1.2	0	16.0	1
151	Leather	2.6	1	3.6	0
152	Shoes	3.6	1	4.8	0
161	Sawing and planing wood	0.6	0	8.7	0
162	Wood products	0.3	0	49.0	1
171	Pulp	1.2	0	206.0	1
172	Paper products	0.8	0	52.9	1
182	Reproduction of recordings	28.0	1	0.0	1
201	Basic chemicals	0.3	0	244.4	1
202	Pesticide and other agrochemicals	4.0	1	18.6	1
203	Chemicals used in construction	2.2	1	11.8	0
204	Cleaning products	1.4	0	13.4	0
205	Other chemicals	2.8	1	26.9	1
206	Artificial or synthetic fibers	1.8	1	114.2	1
211	Basic pharmaceutical products	0.4	0	18.6	1
221	Rubber products	2.5	1	35.2	1
222	Plastics	0.9	0	21.4	1
231	Glass products	1.6	1	137.1	1
233	Terracotta products	0.5	0	220.8	1
235	Cement, lime and plaster	0.2	0	494.8	1
236	Structures made of cement, lime, and plaster	3.4	1	34.5	1
237	Finishing of stones	0.5	0	13.1	0
239	Non metallic minerals	16.8	1	52.3	1
241	Basic steel	1.0	0	147.8	1
242	Steel products	0.3	0	66.4	1
243	Other primary products of steel	0.7	0	39.9	1
244	Non ferrous metals	1.4	0	62.3	1
245	Foundry	4.0	1	67.6	1

Trade exposure is the ratio between French imports and French domestic production. Energy intensity is the ratio between energy use and real output.

Table 18: Industry classification: part 2

Code	Industry name	Trade exposure (%)	Trade exposed (0/1)	Energy intensity (toe/million €)	Energy intensive (0/1)
251	Metal elements for construction	2.1	1	5.9	0
252	Metallic containers	5.7	1	12.0	0
253	Steam generators	3.6	1	14.1	0
255	Wrought and stamped metals	3.5	1	34.8	1
256	Treatment and coating of metals	2.1	1	15.7	0
257	Cutlery, tools and hardware	5.6	1	13.1	0
259	Other articles of metal	2.5	1	24.7	1
261	Electronic components and boards	1.6	1	20.3	1
262	Computers	5.8	1	5.1	0
263	Communication equipment	1.3	0	2.7	0
265	Instruments and apparatus for measuring	1.2	0	0.0	1
266	Medical equipment	4.4	1	8.9	0
267	Optical and photographic material	38.1	1	0.0	1
271	Electric motors, generators, transformers	1.0	0	7.7	0
272	Batteries and accumulators	13.4	1	38.3	1
273	Wires and cables	2.2	1	12.3	0
274	Electric lighting fixtures	4.3	1	12.5	0
275	Household appliances	2.6	1	10.9	0
279	Other electrical equipment	4.8	1	9.7	0
281	General-purpose machinery	0.7	0	11.5	0
282	Other machinery	0.8	0	6.8	0
283	Agricultural machinery	3.7	1	9.1	0
284	Metal forming machinery	6.4	1	6.2	0
289	Other special purpose machinery	1.6	1	9.2	0
292	Body and Trailer Manufacturing	0.4	0	7.6	0
293	Automotive equipment	0.7	0	13.0	0
301	Shipbuilding	0.1	0	0.0	1
302	Locomotives construction	4.5	1	8.2	0
303	Aeronautical and space construction	0.1	0	0.0	1
309	Transport equipment	14.4	1	11.7	0
310	Furniture	1.4	0	13.0	0
321	Jewelery	0.4	0	19.4	1
322	Musical instruments	28.4	1	0.0	1
323	Sport equipment	12.2	1	2.2	0

Trade exposure is the ratio between French imports and French domestic production. Energy intensity is the ratio between energy use and real output.