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THE JOINT EFFECTS OF ENERGY PRICES AND CARBON TAXES ON ENVIRONMENTAL AND ECONOMIC PERFORMANCE: EVIDENCE FROM THE FRENCH MANUFACTURING SECTOR – ENVIRONMENT WORKING PAPER N° 154

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Keywords: carbon taxation, energy prices, carbon emissions reductions, firm performance, competitiveness

JEL codes: Q52, Q54, Q58

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Abstract

The paper estimates the effect of energy prices and carbon taxation on firms' environmental and economic performance. The analysis uses data on 8 000 firms that are representative of the French manufacturing sector and observed during 2001-2016. The paper shows that (i) even though a 10% increase in energy prices causes a decline in energy use by 6% at the firm level, this increment has no effect on net employment at the industry level, but it motivates a reallocation of production and workers from energy-intensive to energy-efficient firms. Simulations shows also that (ii) the current carbon tax rate reduced manufacturing CO_2 emissions in 2018 by 5% or 3.6 Mt of CO_2 compared to a no-tax scenario, and that (iii) a further increase of carbon tax in France from its current rate of 45€ to 86€ per tonne of CO_2 would induce a reduction in carbon emissions by 8.7% or 6.2 Mt of CO_2 and a job reallocation for 0.24% of the workforce in the manufacturing sector. Our conclusion calls for complementary labour market policies that minimise costs on affected workers and ease between-firms adjustments in employment.

Keywords: carbon taxation, energy prices, carbon emissions reductions, firm performance, competitiveness

JEL codes: Q52, Q54, Q58

Résumé

Ce papier estime l'effet des prix de l'énergie et de la taxation du carbone sur la performance environnementale et économique des entreprises. L'analyse utilise des données sur 8 000 entreprises représentatives du secteur manufacturier français et observées sur la période 2001-2016. Ce document montre que (i) bien qu'une augmentation de 10 % du prix de l'énergie diminue la consommation d'énergie de 6 % au niveau entreprise, cette augmentation n'a pas d'effet sur la création nette d'emplois au niveau sectoriel, mais génère des redéploiements de productions et de salariés des entreprises intensives en énergie vers d'autres plus économes en énergie. Les simulations montrent également que (ii) la taxe carbone, à son taux actuel, a permis de réduire les émissions de carbone en 2018 de 5 % soit 3,6 Mt de CO_2 par rapport à un scénario sans taxe, et (iii) qu'une augmentation supplémentaire de son taux de 45 € à 86 € par tonne de CO_2 générerait une réduction des émissions de carbone de 8,7 % soit 6,2 Mt de CO_2 et un redéploiement pour 0,24 % des salariés du secteur manufacturier. Notre conclusion préconise de disposer de politiques complémentaires sur le marché du travail qui permettent de minimiser les coûts pour les travailleurs touchés et de faciliter les ajustements effectués par les entreprises.

Mots clés : Taxation du carbone, prix de l'énergie, réduction des émissions de carbone, performance des entreprises, compétitivité

Classification JEL : Q52, Q54, Q58

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Executive summary

Energy taxes are one of the main policy instruments to reduce energy consumption and associated carbon emissions, and several OECD countries including France, Sweden, and the UK have introduced a carbon tax which translates into higher energy prices. The objective of this study is to evaluate whether these market-based policy instruments are effective at reducing carbon emissions and to what extent they affect firm employment and competitiveness. The existence of a potential trade-off between environmental and economic performance is of particular relevance in France, where manufacturing employment decreased by 26% between 2001 and 2016.

The study provides new evidence on the effect of energy price changes on firm-level environmental and economic performance and on industry-level employment based on a unique dataset of 8,000 French manufacturing firms observed from 2001 to 2016. The causal impact of energy prices is identified through an Instrumental Variable method.

The firm-level results show that a 10% increase in energy prices causes a decline in energy use by 6% and in carbon emissions by 9%. However, the energy cost increase has no effect on net employment at the industry-level when accounting for movements of workers' between firms. The analysis shows that the rise in energy prices triggers a reallocation of production and workers from energy-intensive to energy-efficient firms.

These reallocations are consistent with the firm-level results, which indicate that employment declines as energy price increases for large (over 50 employees) energy-intensive firms. In contrast, small firms that keep operating in the market do not reduce employment when the energy price increases.

There are two major policy implications from these findings.

First, carbon pricing policies that increase the energy cost generate employment reallocation between firms. These reallocations are relatively important in basic metal, food product, beverages, wearing apparel, plastic, and machinery. Because these reallocations have redistributive implications and generate costs for laid-off workers, the results call for complementary labour market policies that ease these between-firms adjustments in employment and support workers through training or unemployment benefits.

Secondly, energy taxes and similar market-based carbon pricing policies significantly reduce carbon emissions. Simulations show that (i) the current carbon tax rate of 45 € reduced manufacturing emissions by 3.6 Mt of CO2 in 2018 compared to a no-tax scenario, and that (ii) a further increase of carbon taxes in France from its current rate of 45€ to 86€ per tonne of CO2 would induce a reduction in carbon emissions of the manufacturing sector equal to 6.2 Mt of CO2. A reduction of this magnitude would be consistent with the second carbon budget established by the French low-carbon strategy for the 2019-2023 period.

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. For this reason, many governments around the world have adopted policies to reduce energy consumption. The European Union, for example, has set itself a 30% energy savings target by 2030 and has proposed policies that Member States could adopt to meet this target. France 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 taxes or cap-and-trade programmes, provide an appealing solution because changes in energy prices provide direct incentives for consumers to reduce their energy consumption [Jacobsen, 2015]. This stands in contrast to imposing standards, which are 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, price-based policies impose a cost on consumers through increases in the effective energy price, and policy makers fear that companies may react to such cost increases by reducing output or employment.[1]

The way in which businesses respond to changes in energy prices is informative about the impact of future more stringent carbon pricing policies, which will effectively raise energy prices. Thus, analysing companies' responses to energy price changes has important policy implications. For example, the economic losses among affected businesses may be small 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 firms respond by reducing their consumption of energy services and eventually output and employment. Evidence on firm-level responses to increased cost of energy can therefore enhance our understanding of the ultimate economic consequences of 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) has been 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]

This paper contributes to this debate by performing two analyses utilising a unique dataset that combines firm-level information from a number of databases managed by the French Statistical Office (Insee). These datasets include the energy consumption and expenditure from the EACEI survey (Enquête sur les consommations d'énergie dans l'industrie), financial data from FARES (Fichier complet unifé de SUSE) and FICUS

[1] Some policies are levied at the point of energy generation (e.g., the European Union Emissions Trading System 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.

(Fichier approché des résultats Ésane), patent data from PATSTAT, and pollution abatement investment data from the Antipol survey. The dataset is representative of French manufacturing firms with more than 20 employees.

The first analysis is at the micro-level. We estimate the short-run responses of French manufacturing firms to exogenous changes in energy prices at the micro-level. Our identification relies on the use of the fixed-weight energy price index as an instrumental variable for average energy cost, following [Linn, 2008] and [Sato et al., 2015]. We argue that using average energy cost directly as the explanatory variable would result in biased estimates due to potential endogeneity issues associated with factors that can affect energy demand and prices simultaneously. The index uses industry-wide median 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], thus providing a relevant instrument for observed energy costs.

Our micro-level results suggest that increases in energy prices result in a decline in energy use with an elasticity of 0.6[3] and in a decline in carbon emissions with an elasticity equal to 0.9. French firms are more sensitive to changes in fossil fuel prices than to changes in electricity prices. We also find that, for firms having more than 50 employees only, employment can decline as energy price increases. However, the employment elasticity (0.2) is smaller than that of the energy use elasticity, suggesting that affected firms manage to partly reduce their energy intensity other than through reductions in the size of their workforce. In contrast to large firms, small firms having less than 50 employees (which represent 99% of French manufacturing firms and 28% of the workforce) do not reduce employment when the energy price increases.[4]

One of the main contributions of this paper is to complement the firm-level analysis by an industry-level analysis. The firm-level analysis looks at the effect of the energy price only on the employment of existing firms. It does not look at the effect of the energy price on new employment through the entry of new firms on the market. Therefore, the firm-level analysis is silent by design on these potentially positive effects on jobs. In contrast, the industry-level analysis looks at both job destruction and creation and can provide an indication of the energy price effect on net job creation. However, it relies on stronger identifying assumptions than the micro analysis.[5]

The main advantage of the industry-level analysis is that, contrary to energy use which is observed only for a sample of firms included in the annual survey on energy consumption, employment is observed for the entire population of manufacturing firms. This allows us to compute job destruction and job creation metrics proposed by [Davis and Haltiwanger, 1992] for all manufacturing industries and correlating these with the

[3] 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).

[4] There are other differences between large firms and small and medium-sized enterprises. Large firms react by filing more patents. A part of the capital expenditure takes the form of investment in end of pipe technologies for the abatement of air, water, and waste pollution presumably because firms replace their existing energy inefficient abatement technologies. It is also possible that firms clean up by reallocating production between plants but that is something we cannot test or measure with our data.

[5] The exogeneity of the fixed-weight energy price index is ensured at the micro-level since no individual firm can influence the fuel prices used to construct the index.

energy price index. We find that energy price variation does not affect aggregate employment in manufacturing industries. In other words, the net effect of energy price variations on the total level of jobs is null. Among the factors that drive this result are two opposing forces: (i) a reduction of employment in large and energy-inefficient firms in the short run as found in our firm-level analysis and (ii) an increase in employment in energy-efficient firms (including new entrants) due to output reallocation between firms.

We illustrate our findings with three simulation exercises based on our micro-econometric estimates. First, we measure change in employment due to energy price variation as a share of total employment in the manufacturing sector. We find that the employment reallocation due to the energy price represents 0.25% of total employment on average but varies greatly across industries. Variation in the energy price causes substantial workers reallocation in food products (0.73%), basic metals (0.61%), and wearing apparel (0.53%) but very little reallocation in pharmaceuticals (0.07%), paper (0.05%), and textiles (0.04%).

Second, we estimate ex-post the impact of the carbon tax on the French manufacturing sector's CO2 emissions and employment between 2014 and 2018. We find that the current carbon tax at 44.6 € per tonne of CO_2 reduced emissions by 3.6 Mt in 2018 with no impact on total employment.

Third, we simulate the effect of the French carbon tax on CO_2 emissions and employment for 19 sectors. We examine the consequences of doubling the rate of the French carbon tax currently equal to €44.6 per tonne. Assuming our sample of firms is representative of the French manufacturing sector, we find that the carbon tax increase would reduce total carbon emissions by 6.2 Mt of CO_2 and induce a reallocation of 0.24% of the manufacturing workforce.[6] The reallocation of labour is relatively important in the basic metal, food product, beverages, wearing apparel, plastic, and machinery where it represents at least 0.3% of the workforce. These figures suggest that the French carbon tax can reduce carbon emissions significantly but would also lead to significant reallocation of workers between firms and industries, even if it would likely leave total employment unaffected.

Our study is related to the literature that looks at the relationship between energy prices and energy use. As a general finding, the empirical literature has identified non-negligible fuel and electricity price-elasticities, especially in the long run [Houthakker, 1951; Taylor, 1975; Bohi and Zimmerman, 1984; Al-Sahlawi, 1989; Espey, 1996; Brons et al., 2008; Havranek et al., 2012; Labandeira et al., 2017]. Nonetheless, none of these studies have characterised the manner by which firms reduce their energy consumption.

In addition, this paper relates to studies looking at the effect of the energy price on the binary adoption of energy efficient technologies by manufacturing firms [Pizer et al., 2001; Anderson and Newell, 2004]. We contribute to this literature by estimating the effect of the energy price on the number of successful patent applications and on pollution abatement capital expenditure.

More generally, the study is related to the growing literature evaluating environmental policies on firm-level environmental performance [Greenstone et al., 2012; Walker, 2013; Martin et al., 2014; Wagner et al., 2014; Flues and Lutz, 2015; Gerster, 2015; Pertrick and Wagner, 2018]. In general, firms respond to environmental policies by

[6] Our simulation takes into account that energy intensive firms that are under the EU-ETS or exposed to carbon leakage do not pay the full carbon tax rate.

cutting down on the regulated energy inputs and reducing CO2 emissions. However, the results in terms of the trade-off between environmental goals and economic outcomes remain highly mixed. There are two main reasons that explain these differences in the literature. First, the previous studies look at different measures of economic performance. Second, heterogeneity between firms and sectors are not systematically accounted for. In this paper, we address these two concerns by looking at many different measures of economic performance: output, employment, investment, and patents and we highlight the important differences between large firms, medium-sized firms and small enterprises.

This paper shares similarities with [Marin and Vona, 2017] who analyse the impact of energy prices on employment and environmental performance of French manufacturing plants. However, our study is different in several respects. First, while [Marin and Vona, 2017] focus on surviving plants' response to energy price variation, we examine the effect of energy price variation on net job creation at the industry level and stress the importance of output reallocation. Second, we take firms as our unit of observation instead of plants. This allows analysing the effect of the price on real output, investment, employment, and patenting and exploring the heterogeneity between small and medium-sized enterprises (SMEs) and large firms.[7] Third, in addition to measuring energy use and employment elasticities, we characterise the manner by which firms reduce energy use per unit of output by examining fuel choice, input substitution as well as the investment in pollution abatement technologies. Fourth, we test for heterogeneous effects of the energy price on several dimensions: energy intensity and firm size.[8] Finally, we simulate the effects of an increase in the French carbon tax on the employment and CO_2 emissions of 19 sectors using sector specific econometric estimates.[9] We believe this paper will inform policy makers further in designing jointly appropriate environmental and economic policies.

The paper is organised as follows. Section 2 briefly discusses our unique dataset. Section 3 contains the empirical analysis of the effects of energy price on surviving firms' environmental performance, economic performance, input substitution, and technology adoption. Section 4 analyses the net effect of energy price variation on industry level job creation. Section 5 shows where energy price variation has led to employment reallocation in manufacturing employment, measure the effects of the carbon tax between 2014 and 2018, and simulates the effect of doubling the carbon tax rate on manufacturing CO2 emissions and employment. Finally, section 6 concludes the study.

[7] I also measure investment response and use more recent data than [Marin and Vona, 2017] who cover 1997-2010.

[8] [Marin and Vona, 2017] also explore heterogeneity but they estimate coefficients using separate sample while we estimate heterogeneous effects on a single sample in order to avoid sample selection issues.

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

2. Data

2.1. Source and definition

Our main dataset consists in an unbalanced panel of 8,000 French firms observed yearly from 2001 to 2016 and representative of the entire manufacturing sector with the exception of the industries of tobacco, arms, and ammunition.[10] We obtain this sample by merging 2 datasets: an 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 information on the consumption of electricity, natural gas, coal, oil, and other fuels at the plant level. We combine CO_2 emission factors from the French Environment and Energy Management Agency (Ademe) with fuel use to compute CO_2 emissions from fuel combustion. These energy consumption data are available at the plant level. However, our level of analysis is the firm since data on economic outcomes 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. For multi-plants firms, we would need data for all plants. To verify whether this is the case, we proceed as follows. First, we compute the sum of employees for the plants for which the energy data is available using the list of manufacturing establishments 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 90% of the firm's total number of employees, we consider that the sum of energy expenditure and use of its plants is a measure of the firm's total energy expenditure and use. The 90% threshold represents a trade-off between (i) minimizing the error in measuring the firms' total energy use and (ii) maximizing the number of observations in order to have a representative sample. Increasing the threshold decreases the error in measuring the firms' total energy use but also leads to the loss of firms in our sample. Using a very high ratio presents the risk to drop firms that have establishments such as office buildings that do not consume large quantities of energy and would never be sampled in the EACEI.[11]

The EACEI contains all plants having more than 250 employees. Other plants having between 20 and 249 employees are sampled via a two-level stratification based on the employment class and on the plant location. Plants having less than 20 employees are not included in the sample. The response rate is very high. For example, 90% of the plants replied to the 2014 survey.

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. Data on patent filings come from the PATSTAT database. We match patent filings with firms using Bureau van Dijk's Orbis-PATSTAT dataset.

[10] We include some firms from the coking and refining industry (NACE 19) in our estimations, but their number is too small to deliver statistics at the industry level.

[11] In Table C.6. and Table C.7. we respectively use a 100% threshold and an 85% threshold and show that our results are not sensitive to the 90% threshold.

In order to analyse the effect of the energy price on investment in pollution abatement technologies, we use plant-level data from the Antipol survey maintained by Insee. Every year, Antipol asks plants how much they invest in pollution abatement technologies. For the latest years, the survey is mandatory for plants with more than 250 workers. Plants between 20 and 249 workers are randomly sampled over economic activity and number of employees. Investment is broken down by environmental media, including air, water, waste, and soil. The survey also makes the distinction between end-of-pipe and integrated technologies. As the amount of data for integrated technologies is much lower than for end-of-pipe technologies, we focus only on the latter.

Note that the dataset used to test the effect of energy price on investment in pollution abatement differs from our main dataset. First, it is at the plant level and not at the firm level and second, the data availability for investment measures is lower than the availability of the energy use data. Therefore, the investment dataset is smaller than our main firm-level dataset. Summary statistics can be found in Annex A.

Energy cost varies greatly across firms and has increased significantly. Figure 1 shows the evolution of the average energy cost during our sample period. On average, the energy cost increased from 500 euros per tonnes of oil equivalent (toe) in 2001 to 900 euros per toe in 2016. This overall increase is consistent with the trend of the West Texas Intermediate crude oil price.

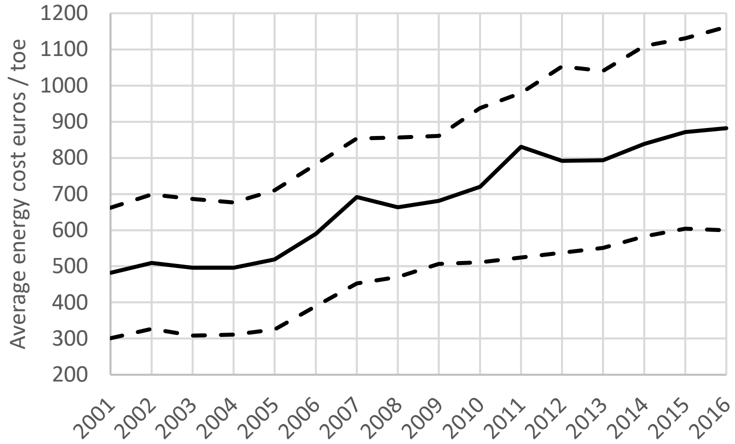
The ranking of the industries is consistent with expectations. Figure 2 shows the average energy intensity by 2-digit manufacturing industry.[12] The least energy intensive industries include leather, computer, electrical and machinery while the most energy intensive industries include non-metallic minerals, chemicals, basic metals, and paper.

Figure 3 plots energy intensity as a function of the average energy cost. The figure shows that there is substantial variation in both energy intensity and energy cost between French industries. Energy is the most expensive in the wood products industry with 820 euros per toe followed by the non-metallic minerals, metal products, and furniture industries with 750 euros per toe while it is the least expensive in the food products and basic metal industry with 570 euros per toe. Energy costs 26% more for firms operating in non-metallic minerals than for firms operating in the basic metal while the energy intensity is the same for the two industries. A similar observation can be made between wood products and the food industry where the difference in energy cost reaches 42% on average.

What causes such variation in the energy cost across industries? Figure 4 and Figure 5 provide some answers by respectively showing the distribution of the electricity price and of the natural gas price for different classes of energy expenditure. There exist significant quantity discounts. For both fuels, we observe that the cost decreases monotonically in the amount of fuel purchased. Firms purchasing less than 50 MWh of electricity pay 100 euros per MWh on average while firms purchasing more than 5,000 MWh pay 55 euros per MWh on average. Firms purchasing less than 500 MWh of gas pay 40 euros per MWh on average while firms purchasing more than 50,000 MWh pay 25 euros per MWh on average.

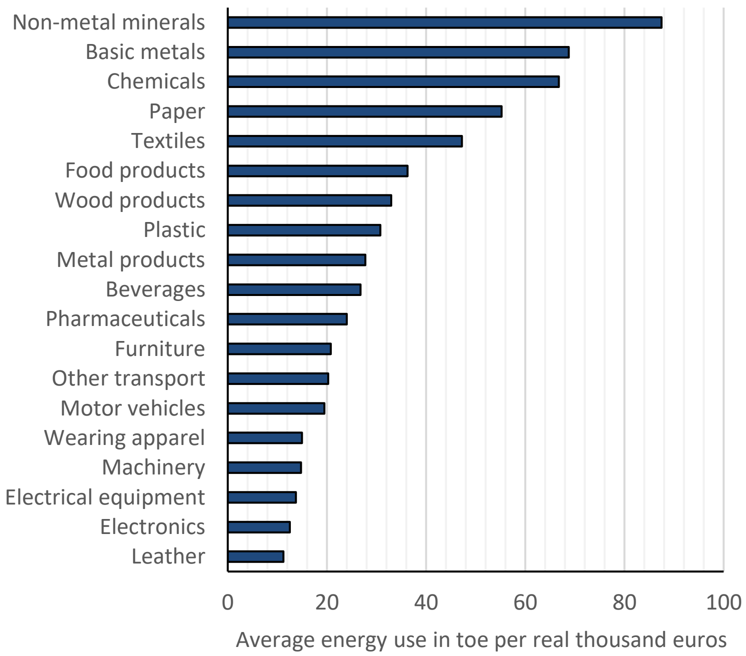
[12] Average are computed over 2001-2016.

Figure 1: Evolution of the average energy cost



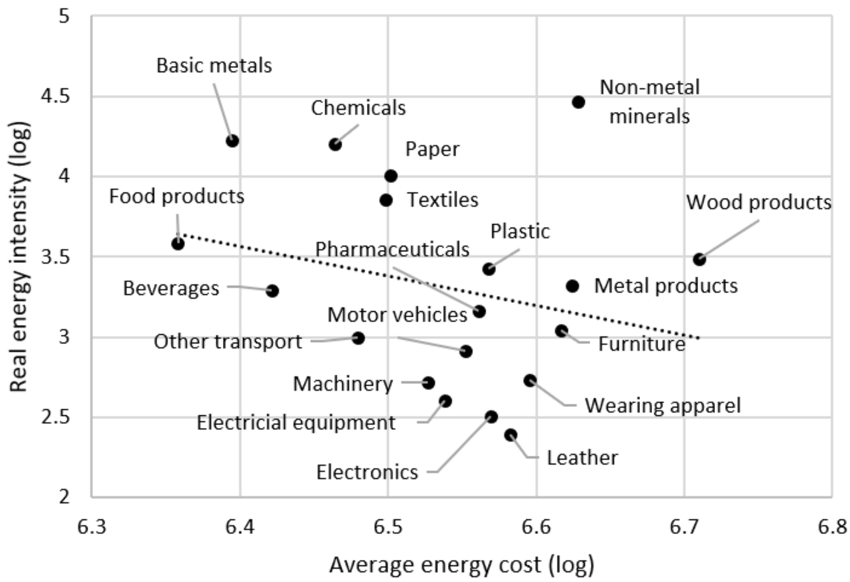
Note: Dotted lines represent the 10th and the 90th percentiles of the distribution.
Source: Authors' calculation.

Figure 2: Energy intensity by industry



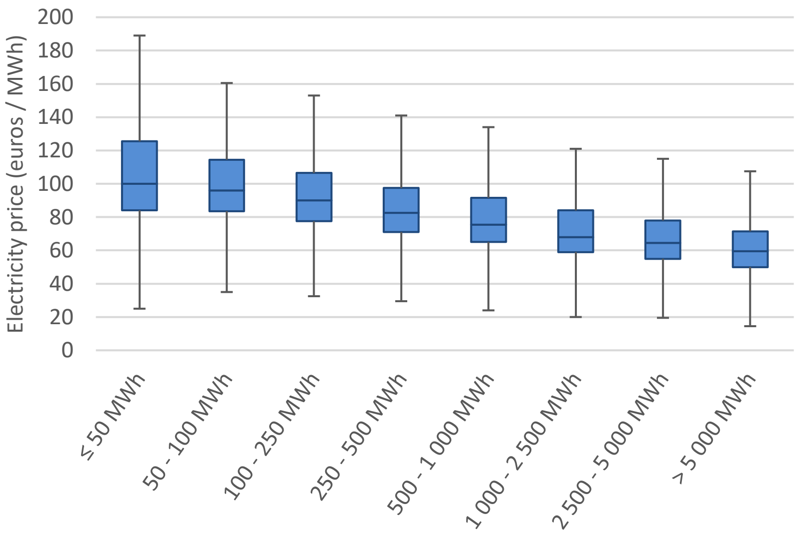
Note: Average computed over 2001-2016. Source: Authors' calculation.

Figure 3: Energy intensity and average energy cost



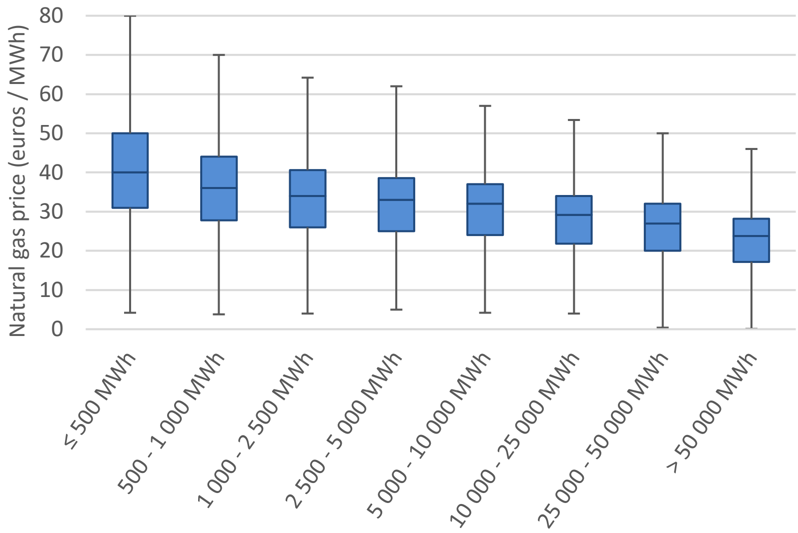
Note: Average computed over 2001-2016. Source: Authors' calculation.

Figure 4: Distribution of electricity price for different class of electricity consumption



Note: Authors' calculation using EACEI data.

Figure 5: Distribution of natural gas price for different class of natural gas consumption



Note: Authors' calculation using EACEI data.

In this study, we focus on the four main fuels (electricity, natural gas, heating oil, and butane propane) consumed in the French manufacturing sector, but this is not restricting. Electricity accounts 58% of total energy use for the average French manufacturing firm. Natural gas accounts for 28%, heating oil for 6%, and butane propane for 4%. In addition, for 90% of the French manufacturing firms, these four main fuels account for more than 95% of total energy consumption.13 To preserve the number of observations in our sample and for clarity, we restrict our analysis to these main four fuels.14 Table A.1 and Table A.2 respectively show the summary statistics for the main dataset and the investment dataset.

[13] Moreover, the correlation between average energy cost with all fuels and average energy cost with the 4 selected fuels is 0.98.

[14] Our results are robust to this restriction.

3. The direct effects of energy price variation at the firm level

3.1. Methodology

3.1.1. Econometric model

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

$$y_{it} = \beta_0 + \beta_1 Cost_{it-1} + \beta_2 X_{it-1} + \mu_i + \gamma_t + \varepsilon_{it} \qquad (1)$$

where y is an outcome variable for firm i at time t, such as energy use, the number of workers, real output, etc. $Cost$ is the log of average energy cost measured by the ratio between expenditure in electricity, natural gas, heating oil, and butane propane 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 included in the European Union Emission Trading Scheme (EU-ETS) starting in 2005 and the average age of the firm's plants, μ_i are firm fixed-effects, γ_t are year dummies, and ε_{it} is the error term. We estimate equation (1) with a fixed-effects estimator that allows us to control for time-invariant and firm-specific characteristics μ_i that may be correlated with the energy price index as well as with the outcome variables. This method captures differences across firms operating in industries that vary substantially in terms of energy intensity. For example, 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.

The year dummies γ_t control for consumer demand and fuel price fluctuations 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 carbon intensive and are eligible to fuel tax discounts.[15] All regressors are lagged by one year. This reflects the time firms need to react to new average fuel prices.[16] We compute robust standard errors clustered at the firm level.

It is possible that firms react to energy price increases differently depending on their size. For instance, [Sadorsky, 2008] finds evidence that changes in oil prices have the biggest effect for medium-sized firms in comparison to small and large firms.[17] Why

[15] Another option is to interact the ETS dummy with our industry x year dummies to account for change in the electricity price that might be caused by the EU-ETS. When we do that, we obtain very similar estimates that are available upon request.

[16] We obtain similar results regarding energy use and employment when the regressors are not lagged as reported in Table C.4. The substitution from fossil fuel towards electricity is stronger than in our baseline. In Table C.8 and C.9, we go further by estimating a dynamic lag model which includes two lags in the regressors in addition to contemporaneous regressors. We find that most of the effect occurs at the first lag.

[17] In Sadorsky (2008), size is based in terms of actual millions of dollars of sales, small firms are those with annual sales less than or equal to \$140.07 million, large firms are those with annual

would the energy cost have a different effect on firms of various size categories? Some studies support the idea that big firms have more resources and capabilities, achieve economies of scale and have greater economic performance as measured by productivity [Caves and Barton, 1990] or profitability [Bradburd and Ross, 1989]. This stream of literature suggests that small companies have more difficulty adapting their input mix and therefore be more exposed by rising energy prices. Another part of literature finds that small firms might be more productive than large ones because of their greater innovation potential [Hansen, 1992; Acs et al., 1991] and face lower organisational problems than large companies [Aiginger and Tichy, 1991]. Considering that 90% of firms in the French industry are SMEs, any difference with bigger firms has important policy implications.[18]

To test for heterogeneous effects of the energy price, we augment model (1) with two interaction terms: (i) an interaction between the average energy cost and a dummy variable $Small_{i0}$ equal to 1 if the firm has less than 50 employees in the first year it is observed and (ii) an interaction between the average energy cost and a dummy variable $Large_{i0}$ equal to 1 if the firm has more than 250 employees in the first year it is observed. The augmented model can be written as follows:

$$y_{it} = \alpha_0 + \alpha_1 Cost_{it-1} + \alpha_2 Cost_{it-1} \times Small_{i0} + \alpha_3 Cost_{it-1} \times Large_{i0} + \alpha_4 X_{it-1} + \mu_i + \gamma_t + u_{it} \quad (2)$$

Estimating the model on a unique sample with interaction terms ensures that we do not introduce some sort of sample selection bias in the different regressions.

3.1.2. Instrumental variables

We estimate model (1) and model (2) using a Two Stage Least Square (TSLS) estimator. This estimator is superior to the Ordinary Least Square (OLS) estimator because the effect of $Cost_{it}$ is confounded with the effects of unobserved factors that cause change in y_{it} and are potentially correlated with $Cost_{it}$. The TSLS estimator that allows to recover the causal effect of $Cost_{it}$ requires the use of an instrumental variable. In our case, we use an exogenous energy price index as an instrument for the energy cost (see Box 1).

We observed significant variation of the average energy cost over time in Figure 1 and significant variation of the energy cost across industries in Figure 2. However, in order to identify the effect of the energy cost, we need within-firm level variation in both the average energy cost and the energy price index over time. To verify whether this is the case, we rescale 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 standard variation equals 20% for the average energy cost and 15% for the energy price index. Therefore, we should have enough within-firm level variation to estimate our models.

sales larger than or equal to $5.38 billion dollars. Medium firms are those with annual sales greater than $140.07 million and less than $5.38 billion dollars.

[18] In our sample, 80% of the firms are SMEs. The EU commission and the French administration define SMEs as firms having a staff head-count lower than 250.

Box 1. Fixed-weights energy price instruments

Relevance

In equation (1) and (2), y_{it} and $Cost_{it}$ are chosen simultaneously by the firm. Firms can influence the fuel prices they face by changing their fuel use as well as their output level or the technologies they use. 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. For instance, we expect the OLS estimator to be biased upward as unobserved firm efficiency or management capacity are negatively correlated with energy use and $Cost_{it}$.

Figure 6 shows the distribution of electricity and natural gas price for each 3-digit industries and illustrates that firms operating in the same (narrowly defined) industries face very different prices. These differences come from quantity discounts and highlight the problem of using firm-level energy cost in an OLS regression.

To address this simultaneity bias, we use an exogenous variation in the fuel price as instrumental variable for the energy cost. More specifically, we follow [Sato et al., 2015] to compute the following fixed-weight energy price index:

$$FEPI_{it} = \sum_j w_{i0}^j \ln\left(p_{kt}^j\right) \qquad (3)$$

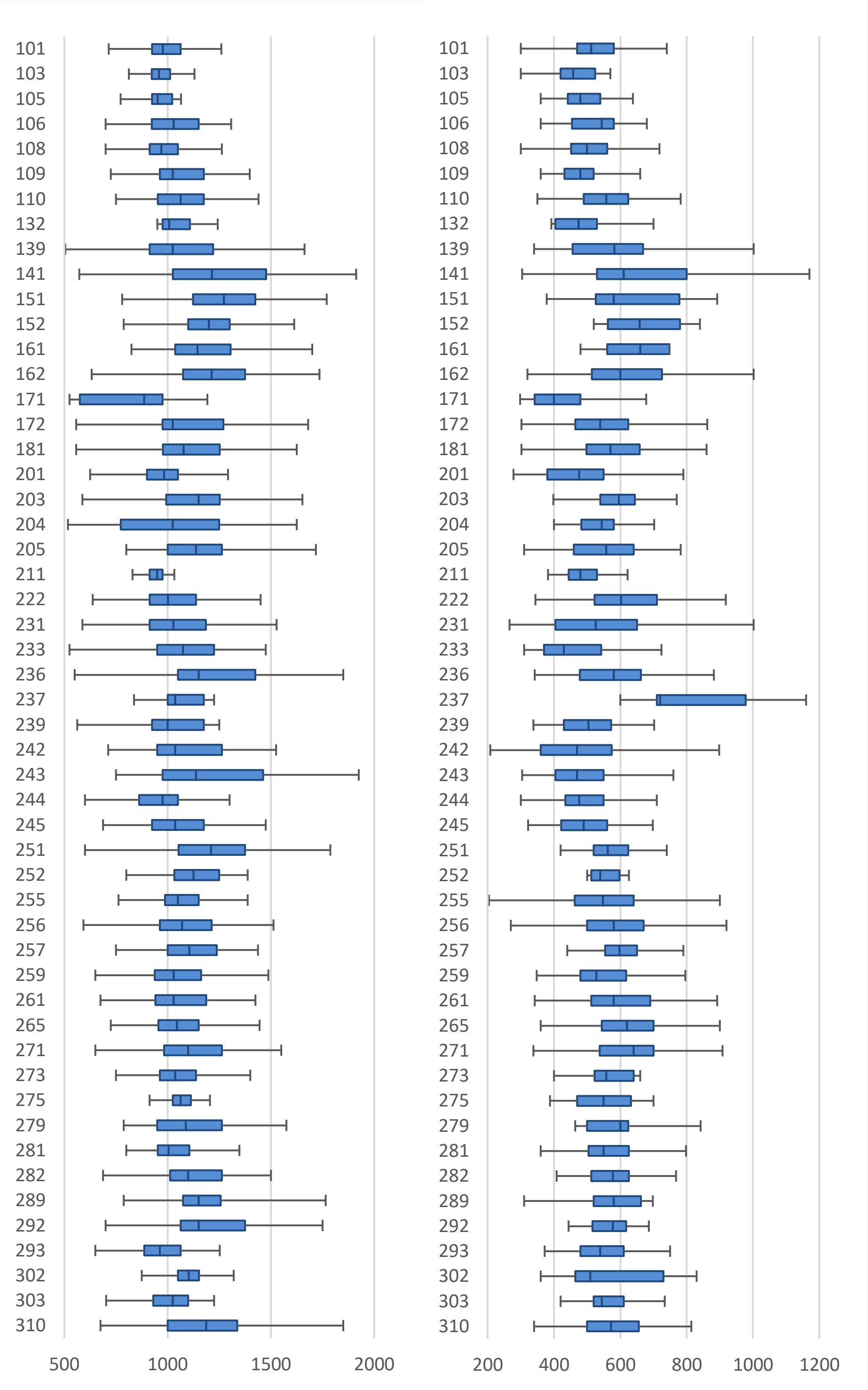
where w_{i0}^j is the share of fuel f in total energy use of firm i at the pre-sample year 0 and p_{kt}^j is the median price of fuel f for the 3-digit industry k in which firm i operates at year t.[19]

The advantage of pre-sample weights is twofold.[20] 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.

[19] [Linn, 2008] uses a fixed-weight energy price index where the fuel weights are computed at the level of a US state. Here total energy use is simply the sum of use of electricity, natural gas, butane propane, and heating oil.

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

Figure 6: Distribution of electricity and natural gas price by industry



Note: Electricity price in EUR/toe in the left panel and natural gas price in EUR/toe in the right panel. 10th percentiles, standard deviation, median, and 90th percentiles for the year 2015

Exogeneity

The within-firm variation thus comes from the industry-level fuel prices. In comparison to fuel prices actually paid by firm i, the industry-level median fuel prices p_{kt} can be assumed to be exogenous to firm i and vary across time. The validity of FEPI as an instrumental variable depends on this assumption.[21] Note that the FEPI can also be computed at the industry level. We expect FEPI to be positively correlated with the average energy cost. We test for under-identification to check the strength of our instrument. Note that the firm fixed-effects also control for the historical fuel mix, used in the computation of the energy price index, which is likely correlated with future energy consumption and competitiveness.[22]

3.2. The estimated effects of energy price variation at the firm level

3.2.1. Energy cost variation affects carbon emissions more than employment

Table 1 shows the estimated effects of the (instrumented) energy cost on firm energy performance and economic performance.[23] We find that an increase in the energy cost is associated with a statistically significant reduction in the energy use. In particular, a 10% increase in the energy cost leads to a decrease of 5.9% of the energy use. The reduction of fossil fuel amounts to 6.5% and is larger than for electricity, which goes down by less than 1.5% and is statistically insignificant. Consistently, the reduction in CO_2 emissions, equal to 9.2%, is larger than the energy use reduction because the combustion of fossil fuel generate more CO_2 than electricity use.[24] This difference in magnitude might be due to the evolution of relative fuel prices. Real electricity prices have increased by 47% over the sample period but this figure equals 59% for butane/propane, 67% for natural gas, and 88% for heating oil.[25] The further decrease in fossil fuel might also be due to electricity being less substitutable.

We also find evidence that changes in energy costs affect some dimensions of firms' economic performance but not all. Table 1 shows that an increase of 10% in the energy cost lowers employment by 2.2%. This elasticity is much lower than the estimated elasticity for energy use and CO_2 emissions.[26] Moreover, the effect of energy price on real output and investment is not statistically different from 0. To enhance our

[21] Table A.3. in the appendix shows that there is a significant variation in the fuel prices between firms operating in the same sector. This reflects quantity discount that makes the actual price paid by each firm unique.

[22] When the dependent variable is the 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.

[23] See appendix for the test on the strength of the instrumental variables used.

[24] The emission factor is 2,750 kg CO_2/toe for natural gas, 3,700 kg CO_2/toe for domestic heating oil, 3,170 kg CO_2/toe for butane/propane, and 582 kg CO_2/toe for electricity.

[25] See Table A.4.

[26] 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%.

understanding of firms' adjustments, we investigate in the next section whether changes in the energy price lead to input substitution, fuel substitution, and change in energy intensity.

In Box 2, we perform robustness checks by varying key parameters of our methodology. The results are robust to using different lags of the main explanatory variables, to varying the threshold used to consolidate plant-level data at the firm level, and to the sampling weights used in a weighted regression.

3.2.2. Higher energy prices lead 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 and employment. In this section, we test whether the energy cost has an impact on energy intensity. We then explore through which channels the changes in energy intensity occur. Do firms reduce their energy intensity through input or fuel substitution or through the adoption of cleaner technologies?

Table 2 shows the effect of the energy cost on energy intensity, energy use per worker, energy use per material, energy use per capital, and the ratio between electricity use and fossil fuel use. The effect of a 10% increase in energy cost on energy intensity is equal to -5.2% and is statistically significant.[27] We find some evidence that labour, material, and capital decrease significantly less than energy use when the energy price increases. A 10% rise in the energy cost reduces energy use per worker by 3.7%, energy use per material by 4.2% and energy use per unit of capital by 5.4%. In addition, we find that the same increase in the energy price increases relative electricity use by 6.4%. Our results suggest that firms reduce their energy intensity by decreasing energy use more than the other inputs and reduce their CO2 intensity by increasing electricity use relative to fossil fuel use.

[27] For an increase of 10% in the energy cost.

Box 2. Robustness checks

Contemporaneous effects of energy price variation

In our baseline model, the regressors of model (1) are one year lagged to make sure we capture the effect of the energy cost variation on economic outcomes. If energy use is highly flexible, employment is usually not. In Table C.4. and Table C.5., we estimate model (1) where the regressors are not lagged. We find results that are similar to our baseline estimation. The only difference is the stronger substitution of fossil fuels for electricity in the case of cotemporaneous regressors.

Sensitivity analysis for the merge between firm level data and plant level data

To merge our plant-level energy dataset and our firm-level fiscal dataset, we verify that the sum of plant-level employment covers at least 90% of the employment observed at the firm level. There exists a trade-off between comprehensiveness of the energy data requiring a high threshold and the number of observations in our final estimation requiring a threshold that is not too high. We show that our choice of threshold does not affect our results. We use an employment threshold of 100% in Table C.6 and a threshold of 85% in Table C.7. Our estimation results are highly similar despite the change in the measurement of environmental variables and in the sample size.

Dynamic effects of energy price variation

In our baseline model (1), we measure the short run effects of the energy cost variation. However, it is possible for changes in the energy cost to have impact that are persistent over time. We test this hypothesis by augmenting model (1) with two lags of the regressors. The results are available in Table C.8 and Table C.9. We find that firms react most to energy price variation of the two years before. When we add the cumulated effects of a 10% change in the energy cost over the three years, we find that energy use is reduced by 5.8%, CO_2 emissions by 9.2%, and employment by 2.7% on average.

Sampling weights

In the energy survey, firms having more than 50 employees are automatically included in the sample. Smaller firms are randomly sampled over two strata: size and industry. Consequently, smaller firms could be underrepresented in the baseline estimation so that the estimated coefficients correspond only to the population of big firms. To verify at which point this might be the case, we estimate model (1) using a weighted TSLS regression. The weights used come from the energy survey and are the inversed of the probability of the firm to be sampled. Table C.13 and C.14 show estimation results that are very similar to our baseline results. Therefore, we conclude that our estimation does not suffer from the sampling method used in the energy survey.

Table 1: The effect of energy price on environmental performance and economic performance

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.592***	-0.144	-0.649***	-0.920***	-0.223***	-0.077	-0.365
	(0.111)	(0.107)	(0.170)	(0.143)	(0.065)	(0.074)	(0.258)
Firm age in years	-0.030***	-0.038***	-0.014	-0.023***	-0.032***	-0.033***	0.004
	(0.007)	(0.007)	(0.009)	(0.007)	(0.004)	(0.004)	(0.012)
ETS (0/1)	0.019	-0.038	0.081	0.063	0.061**	0.075***	0.032
	(0.037)	(0.036)	(0.061)	(0.043)	(0.026)	(0.029)	(0.074)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	45,903	45,893	40,788	45,903	45,903	45,903	36,327
Number of firms	8,002	7,999	7,048	8,002	8,002	8,002	7,168
KP LM statistic	388	388	334	388	388	388	304

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 (FEPI). The first-stage regressions is reported in Table B.1. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Table 2: The effect of energy price on energy intensity and input substitution

	Energy intensity (in real terms)	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost)	-0.515***	-0.369***	-0.423***	-0.541***	0.638***
	(0.112)	(0.111)	(0.142)	(0.125)	(0.171)
Firm age in years	0.003	0.003	0.000	0.001	-0.016*
	(0.006)	(0.007)	(0.008)	(0.007)	(0.008)
ETS (0/1)	-0.056	-0.041	-0.088**	-0.022	-0.123**
	(0.037)	(0.034)	(0.040)	(0.042)	(0.053)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	45,903	45,903	45,903	45,903	40,778
Number of firms	8,002	8,002	8,002	8,002	7,045
KP LM statistic	388	388	388	388	333

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 (FEPI). The first-stage regressions are reported in Table B.1. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

3.2.3. Small, medium-sized, and large firms react differently

Are the coefficients estimated in the previous section the same for all French firms or do they depend on firm size? Table 3 reports the interaction terms with a dummy variable equal to 1 when the firm's number of employees is lower than 50 and a dummy variable equal to 1 when the firm has more than 250 employees.[28] We find that small, medium-sized, and large firms react differently in terms of both environmental and economic performance.

The larger the firm, the more it improves its environmental performance in response to higher energy cost. A 10% increase in the energy cost leads to a reduction of energy use by 6% for medium-sized firms and by 8.5% for large firms while the effect is negative but not statistically significant for small firms. Small and medium-sized firms reduce their fossil fuel use by 6% while large firms reduce it by 8.6%. The difference in magnitude also exists for carbon emissions reduced by 7% by small firms, by 9% by medium-sized firms, and by 11% by large firms.[29] Do large firms reduce more their environmental impacts because they reduce their output more?

[28] These dummies are computed based on pre-sample value of employment to avoid endogeneity. The coefficients are obtained by the estimation of model (2).

[29] The coefficients for SMEs are obtained by the addition of the elasticity coefficient and the interaction coefficients.

The results suggest that it is part of the explanation. Large firms reduce their output by 2.6% while medium-sized does not change their output. Surprisingly, small firms increase their output by 1.4%. The responses in terms of employment also greatly differ. We find that a 10% increase in the energy cost does not affect employment of small firms but reduces it by 2.6% for medium-sized firms and by 5.5% for large firms. Finally, only large firms reduce their level of investment as response to a higher energy cost.

Does this mean that small firms are less affected than larger firms when the energy cost increases? Not necessarily because our estimation results concerns only firms that stay in the market. It is possible that some small firms must exit the market because of the energy cost increase while large firms remain in the sample.

There are several hypotheses on why larger firms reduce employment but not smaller surviving firms. First, large firms are more efficient than small firms not only because of economies of scale but also because they can incur the fixed cost in equipment or strategies that improve their energy efficiency. Smaller firms have more room for energy efficiency gains than larger firms. Both types of firms reduce their energy use, but large firms cannot reduce energy use further without cutting into output and by extension lowering employment. This interpretation relies on the assumption that small firms do not minimize their production cost. The idea is similar to the [Porter and Van der Linde 1995]'s argument where a sufficient energy price increase triggers the reorganization of the firms' production that unveils possibilities to reduce cost.

Second, only large firms can afford the fixed cost to offshore part of their production abroad and thus reducing the employment that goes with it. This interpretation is consistent with the finding that real output of large firms is reduced in lower proportion than employment in response to energy cost variation. SMEs do not generally have the offshoring option. They either exit the market when they are energy intensive or capture the market shares of exiting firms when they are energy efficient.

Third, small surviving firms are capturing the market share of other small firms that exited the market because of the energy cost increase. That can explain why we observe a positive effect on small firms' output.

Do these significant differences in economic outcomes between large firms and SMEs come from differences in their substitution behaviour? Table 4 shows the input substitution results for the augmented model (2). We find that all types of firms substitute energy for labour, material, and capital in similar proportions. Large firms clean up 0.9% more than SMEs. Finally, smaller firms substitute fossil fuel for electricity 2.8% more than medium-sized and large firms. This greater substitution is consistent with the interpretation that small firms have more room for energy efficiency gain.

Do these heterogeneous effects based on firm size come from difference in energy intensity? We find that it is not the case when we estimate in Table C.11 and C.12 a model with two interaction terms. The first is the interaction between energy cost and an SME dummy while the second is the interaction between energy cost and the pre-sample energy intensity of the firms. As in Table 3, we still find that small firms reduce less their energy use, carbon emissions, investment and employment than large firms. In addition to that, we find that firms that were more energy intensive at the beginning of the period respond with greater magnitude than energy efficient firms. This result is consistent with our expectations. Energy intensive firms have more room to energy efficiency gains but are also more exposed than energy efficient firms in terms of competitiveness.

These results suggest that input substitution plays an important role in the reduction of energy intensity. In Box 3, we go a step further by exploring the effects of energy price variation on the firms' technology.

Table 3: Heterogeneous effects on environmental performance and economic performance

	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(average cost)	-0.606***	-0.163	-0.605***	-0.932***	-0.255***	-0.110	-0.362
	(0.115)	(0.109)	(0.177)	(0.148)	(0.067)	(0.076)	(0.263)
ln(average cost) x Small (0/1)	0.258***	0.321***	0.032	0.222***	0.368***	0.252***	0.285**
	(0.059)	(0.060)	(0.090)	(0.075)	(0.042)	(0.045)	(0.126)
ln(average cost) x Large (0/1)	-0.240***	-0.288***	-0.258***	-0.203***	-0.290***	-0.152***	-0.348***
	(0.049)	(0.051)	(0.067)	(0.055)	(0.038)	(0.044)	(0.095)
Firm age in years	-0.029***	-0.037***	-0.014	-0.023***	-0.032***	-0.032***	0.005
	(0.006)	(0.007)	(0.009)	(0.007)	(0.004)	(0.004)	(0.012)
ETS (0/1)	0.061*	0.012	0.111*	0.099**	0.114***	0.107***	0.089
	(0.037)	(0.036)	(0.060)	(0.043)	(0.026)	(0.029)	(0.075)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	45,903	45,893	40,788	45,903	45,903	45,903	36,327
Number of firms	8,002	7,999	7,048	8,002	8,002	8,002	7,168
KP LM statistic	382	382	333	382	382	382	298

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 small dummy equals 1 when the pre-sample number of workers of the firms is lower than 50. The large dummy equals 1 when the pre-sample number of workers of the firms is higher than 250. The instrumental variables for the average energy cost and the interactions terms are the Fixed weight Energy Price Index (FEPI), the FEPI interacted with the small dummy, and the FEPI interacted with the large dummy. The first-stage regressions are reported in Table B.1. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are carbon emissions from energy consumption.

Table 4: Heterogeneous effects on energy intensity and input substitution

	Energy intensity (in real terms)	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost)	-0.496***	-0.351***	-0.370**	-0.541***	0.561***
	(0.116)	(0.115)	(0.148)	(0.129)	(0.176)
ln(average cost) x Small (0/1)	0.006	-0.110*	-0.115	0.024	0.277***
	(0.057)	(0.060)	(0.078)	(0.068)	(0.088)
ln(average cost) x Large (0/1)	-0.088*	0.050	-0.094	-0.029	-0.034
	(0.049)	(0.044)	(0.066)	(0.057)	(0.062)
Firm age in years	0.003	0.002	0.000	0.001	-0.015*
	(0.006)	(0.007)	(0.008)	(0.007)	(0.009)
ETS (0/1)	-0.046	-0.053	-0.085**	-0.017	-0.103*
	(0.037)	(0.034)	(0.041)	(0.042)	(0.053)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	45,903	45,903	45,903	45,903	40,778
Number of firms	8,002	8,002	8,002	8,002	7,045
KP LM statistic	382	382	382	382	332

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 small dummy equals 1 when the pre-sample number of workers of the firms is lower than 50. The large dummy equals 1 when the pre-sample number of workers of the firms is higher than 250. The instrumental variables for the average energy cost and the interactions terms are the Fixed weight Energy Price Index (FEPI), the FEPI interacted with the small dummy, and the FEPI interacted with the large dummy. The first-stage regressions are reported in Table B.1. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are carbon emissions from energy consumption.

Box 3. The effects of energy price changes on technology development and adoption

Large firms innovate more in response to higher energy price

So far, we show that for large firms a rise in the energy price has a negative effect on employment, real output and investment. In this subsection, we look at the effect of energy price on an additional dimension of competitiveness: innovation output as measured by the stock of patents filed by the firm.[30] In theory, an increase in the energy price can have two effects on innovation. First, there could be a negative scale effect where the firm market share decreases because higher energy prices increase production cost. A smaller market share means that the gains from innovation will be lower, which reduces the firm's incentives to invest in R&D. Second, there could be a positive differentiation effect where firms have more incentive to develop new products to maintain their market share.

Table 5 summarizes our results.[31] We find that a 10% increase in the energy price leads to an increase in the stock of patents of 6.3% for large firms and a decrease of 3.5% for SMEs. Therefore, it is possible that the differentiation effect is stronger than the scale effect for large firms. SMEs innovate less because they have probably lower capacities to do so.[32]

Table 5: Innovation output and energy price index

	Stock of patents
FEPI	0.627***
	(0.202)
FEPI x SME (0/1)	-0.978***
	(0.148)
Firm age in years	-0.022*
	(0.012)
ETS (0/1)	-0.004
	(0.134)
Firm FE	X
Industry x Year dummies	X
Observations	29,513
Number of firms	3,403
Marginal effect of SME	-0.352**
	(0.159)

Note: Robust standard errors clustered at the firm level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The stock of patents is logged. The model is estimated via OLS. FEPI is the fixed weight energy price index.

High energy price spurs investment in pollution abatement

Table 5 shows that changes in energy prices modify the technology of large firms. However, patents do not capture all kind of changes in the firms' technology. First, patents do not capture all kinds of innovation as firms only patent a share of their knowledge as part of their appropriation strategy. Second, patents do not measure technology adoption but rather the development of new technology. To overcome the drawbacks of patents, we also look at firms' investment in pollution control technologies. This is interesting given that these technologies often require large quantity of energy to function. The efficiency of pollution abatement equipment is often positively related to its energy consumption.[33]

Table 6 shows the estimation of model (1) when the outcome variable is investment in pollution abatement and the main independent variable is the exogenous energy price (FEPI).[34] We find evidence that an increase in the energy price is positively associated with investment in air, water, and waste pollution control investment at the plant level.[35] If the energy price increases by 10%, investments in air and waste pollution abatement increase by 7% and investments in water pollution abatement increase by 5%.

Our results suggest that increased energy price not only leads firms to reduce their energy use and therefore their carbon emissions, but also induces firms to invest more in the abatement of emissions of other pollutants. Why would a firm invest in clean water investment when it must reduce its energy use? Because the production of clean water from polluted water requires energy [Barakat, 2011, Gude, 2012]. Therefore, to maintain a given amount of water depollution, the firm has to compensate lower energy use by investing in more energy-efficient water-cleaning machines.

These results highlight the trade-off between using cheaper energy-intensive abatement systems and using more capital-intensive energy-efficient abatement systems. If energy becomes more expensive, then firms have more incentive to invest in more energy efficient abatement equipment to maintain a given amount of depollution.

[30] Stock of patents is used as a measure of knowledge stock in the literature [Keller W., 2004]. More specifically, we measure the discounted stock of patents to account for knowledge depreciation over time using the usual 15% rate commonly used in most literature [Keller W., 2004]. We count patent families and not patent applications so that we count the inventions only once.

[31] We estimate a reduced form equation to obtain the largest amount of observation possible. For clarity, we favour a model with only 1 interaction term.

[32] [Czarnitzki and Hottenrott, 2011] find that small or young firms may face financing constraints for their R&D projects. [Hottenrott, H., and Peters, B., 2012] show that the size of the firm is positively associated with innovation.

[33] For instance, [Mussatti and Hemmer, 2002] explain that high energy venturi scrubbers provides increased collection efficiency for fine and submicron Particulate Matters (PM) but that their capital costs and electrical power requirements are much higher than a conventional venturi. Another example is the incineration of volatile organic compounds (VOCs) which often requires addition of auxiliary fuel such as natural gas to raise the waste gas temperature at the appropriate level [Vatatuk et al., 2000]. Similarly, the reduction of Nitrous Oxide by Selective Noncatalytic Reduction is more efficient at higher temperature [Mussatti et al., 2000]. [Englehardt, 1993] highlights the energy cost of different waste abatement technologies.

[34] We prefer estimating a reduced form equation here because the number of observations are limited. Using energy cost would decrease the number of observations available. This is because FEPI only requires pre-sample fuel consumption weights in order to be computed while the energy cost requires fuel consumption data each year.

[35] As explained in section 2, pollution abatement investment data are available at the plant level. However, it is not feasible to aggregate these data at the firm level because there are too many missing plants.

Table 6: Energy price and pollution abatement investment

	End of pipe investment				
	All	Water	Air	Waste	Soil
FEPI	0.515**	0.537**	0.648**	0.717**	0.008
	(0.246)	(0.274)	(0.314)	(0.301)	(0.314)
Plant age in years	-0.010*	-0.007	-0.012	0.013	-0.026***
	(0.006)	(0.007)	(0.008)	(0.011)	(0.006)
ETS (0/1)	0.142	0.028	0.238*	0.057	0.126
	(0.101)	(0.121)	(0.122)	(0.128)	(0.148)
Plant FE	X	X	X	X	X
Year dummies	X	X	X	X	X
Observations	14,820	14,820	11,334	13,280	12,103
Number of plants	3,879	3,879	3,059	3,852	3,342

Note: Robust standard errors clustered at the plant level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The stock of patents is logged. The model is estimated via OLS. FEPI is the fixed weight energy price index. All outcome variables are logged. Investment to prevent pollution in air, water, and waste are end of pipe investment. Table A.1. shows the summary statistics for the estimation sample.

3.2.4. Exploring sector heterogeneity

So far, we have assumed that the parameter of model (9) are the same for all sectors. There are reasons to believe that the parameters of the model are actually different because sectors vary on many dimensions, such as market demand, the elasticity of substitution between energy and other inputs, or the number of firms operating the sector. Therefore, we estimate model (9) for each NACE 2-digit sector separately. Note that we use an OLS estimator in that case and not a TSLS estimator because the instrumental variable exploits between-industries variation in the fuel price. Therefore, we acknowledge that the sector-level coefficients are probably a lower bound of what the true effect is.[36]

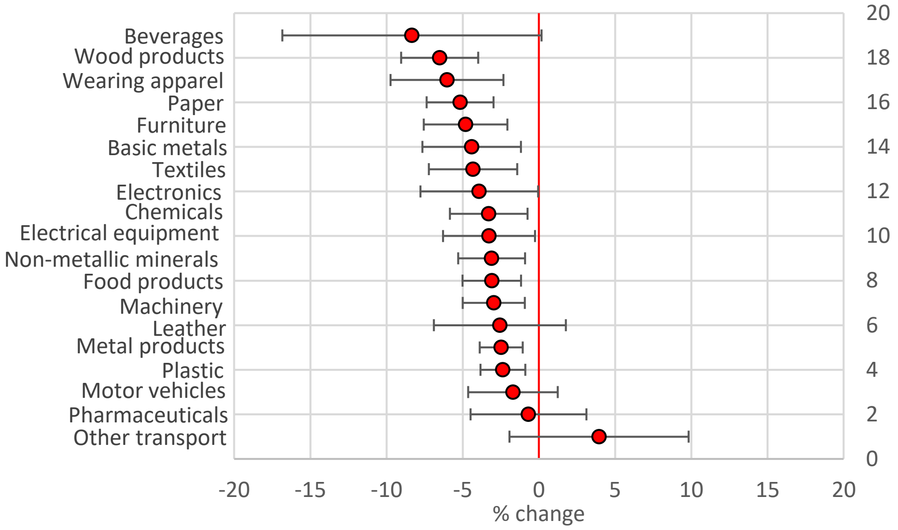
The impact of a 10% increase in the energy cost on CO_2 emissions is displayed in Figure 7 and the impact on the number of workers is displayed in Figure 8.[37] We find that there are large differences between industries. More specifically, 79% of the sectors experience a statistically significant reduction in CO_2, 26% reduce employment, 53% reduce CO_2 but not employment, and 0% reduce employment but not CO_2 emissions in response to higher energy prices. The largest reductions in CO_2 emissions occur in beverages, wood products, and wearing apparel with respectively 8.3%, 6.5% and 6% reduction for a 10% increase in the energy cost. The largest reduction in employment occurs in basic metals, plastics, and food products with respectively 1.2%, 0.78% and 0.75%. These magnitudes are in line with

[36] We expect the OLS estimator to be biased upward as unobserved firm efficiency or management capacity are negatively correlated with employment and $Cost_{it}$. An efficient firm produces the same quantity of output with fewer workers and will manage to bargain better fuel prices.

[37] Detailed results are available in Table A.5.

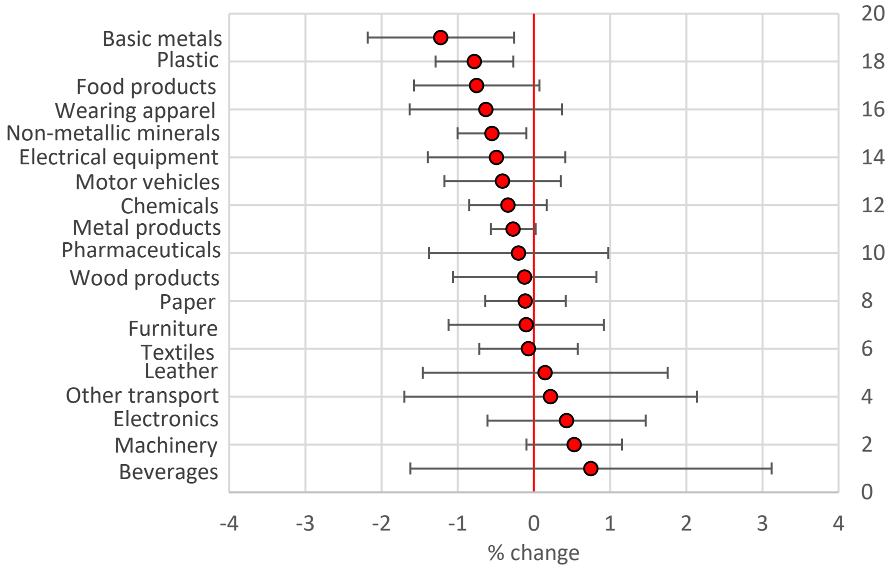
our main results when using the OLS estimator as shown in Table C.1. Table A.5 reports the detailed coefficients along with the average energy intensity in the sector. The effect on workers is more negative for firms operating in sectors that are energy intensive and for which energy expenditure represents a higher share of output.[38]

Figure 7: Change in CO_2 emissions for a 10% increase in energy cost by sector



Note: These confidence intervals are estimated via separate OLS regression.

Figure 8: Change in workers for a 10% increase in energy cost by sector



Note: These confidence intervals are estimated via separate OLS regression.

[38] The estimated coefficient for workers is correlated with energy intensity at -0.45 and with share of energy expenditure in total output at -0.51.

4. The net effect of energy price variation on employment at the industry level

In this section, we estimate the effect of energy price variation on employment at the industry level. This analysis complements the previous firm-level analysis by incorporating between-firms adjustments induced by the energy price variation. Deriving the net effect of energy price on employment is possible because we observe the total number of workers in each industry. A similar analysis on carbon emissions is not feasible since industry-level emissions are not observed.

4.1. Energy price variation has no effect on aggregate net job creation

To analyze the effect of energy prices on employment at the industry level, we use the job flow metrics popularized by [Davis and Haltiwanger, 1992]. In particular, as in [Davis and Haltiwanger, 1992], we compute the job creation rate in industry k at time t, POS_{kt}, as the sum of employment growth of expanding and entering firms within industry k between $t-1$ and t, divided by the size of the industry. This allows to express the flow in terms of a rate:[39]

$$POS_{kt} = \frac{\sum_{i \in k^{+}} |EMP_{ikt} - EMP_{ikt-1}|}{\sum_{i \in k} (EMP_{ikt} + EMP_{ikt-1})/2} \quad (4)$$

Where k^{+} is the subset of firms in industry k that experience positive growth in employment between $t-1$ and t.

Similarly, job destruction is given by the sum of the employment losses at contracting and exiting firms, and expressed as a rate as:

$$NEG_{kt} = \frac{\sum_{i \in k^{-}} |EMP_{ikt} - EMP_{ikt-1}|}{\sum_{i \in k} (EMP_{ikt} + EMP_{ikt-1})/2} \quad (5)$$

Where k^{-} is the subset of firms in industry k that experience negative growth in employment between $t-1$ and t.

Job creation and job destruction rates are used to compute the net change in jobs NET_{kt} inside industry k between year $t-1$ and t:

$$NET_{kt} = POS_{kt} - NEG_{kt} \quad (6)$$

After calculating the job flow metrics, we estimate the following equation:

$$y_{kt} = \alpha_0 + \beta FEPI_{kt-1} + \lambda_t + \gamma_k + \varepsilon_{kt} \quad (7)$$

where $y_{kt} \in \{POS_{kt}, NEG_{kt}, NET_{kt}\}$ is the job flow metric in industry k at time t while $FEPI_{kt-1}$ is the lagged fixed-weight energy price index as previously defined. λ_t and γ_k capture time- and industry-specific effects, respectively. Estimation (7) indicates the direct impact of energy price movements on the variables of interest.

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[39] The size of the industry is computed as the average between t and $t-1$.

Table 7 shows the estimation results. Energy price movements do not have any statistically significant influence on aggregate job creation, job destruction and, most importantly, on net employment.

Table 7: Effect of energy prices on job creation and destruction at the industry level

	Gross job creation rate	Gross job destruction rate	Net job variation rate
FEPI	0.126	0.012	0.114
	(0.167)	(0.029)	(0.173)
Industry FE	X	X	X
Year dummies	X	X	X
Observations	666	666	666
Nr. of industries	61	61	61
Adjusted R^2	0.10	0.38	0.20

Note: Each column corresponds to a seperate regression. Robust standard errors clustered at the 3-digit NACE are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. $FEPI$ is the fixed-weight average energy price.

In the firm-level analysis presented in Section 3. , we find that higher energy prices have a negative effect on the number of workers employed by large firms. This previous result seems at odds with our finding that energy price variation has no effect on net employment at the industry level. These results can coexist because the firm-level analysis focuses on surviving firms only while the industry-level analysis covers all firms, surviving or not. First, the effect of energy price variation on firms entering the market cannot be measured in the firm-level analysis since the these firms are not observed before they join the market. Second, the firm-level analysis reports two average effects of energy price on employment: a negative one for medium-sized and large firms and a insignificant effect for small firms.There might still be heterogeneity within large, medium-sized and small firms. Some surviving firms that are energy efficient might increase their employment because they win market shares from energy-inefficient firms. In other words, output reallocation between firms induced by changes in the energy price leads to employment reallocation between firms.

4.2. Output reallocation offsets the negative employment effect of energy prices

To test wether output reallocation from energy-inefficient firms to energy-efficient firms offsets the negative employment effect found for most surviving firms in the micro-analysis, we proceed in two steps.

In the first step, we decompose industry level energy intensity into two components: (i) a firm-level component reflecting changes in energy intensity for the average firm and (ii) an output reallocation component reflecting changes in output between firms having different level of energy intensity. Our methodology is detailed in Box 4. We find that there is output reallocation from energy-inefficient to energy-efficient firms in the vast majority of sectors.

In the second step, we regress the job creation and job destruction indices on industry level energy intensity and its two components − unweighted energy intensity and output reallocation − in separate estimations at the 3-digit levels that include industry fixed-effects and year fixed-effects. The results are presented in Table 9. We find that output reallocation towards energy efficient firms has no statistically significant effect on net job creation. In other words, output and workers move from energy intensive firms to energy efficient firms without affecting the total level employment. This result is consistent with our finding that the energy price has no effect on net job creation.

If energy price variation is neutral is terms of total employment at the industry level, it is not neutral on workers who change jobs within industries.

Because of data constraint, it is not possible to estimate the effect of higher energy price on carbon emission at the industry level. However, we can expect a net negative effect given that we find a negative short-run impact on surviving firms in the firm-level analysis and that output reallocation towards energy-efficient firms occurs in most sectors.

Box 4. Output reallocation between energy-efficient firms and energy-inefficient firms

To measure output reallocation between energy efficient firms and energy inefficient firm, we follow [Brucal et al., 2018] and compile the aggregate energy intensity measure W_{kt}, which is the average of the firms' individual energy intensities weighted by the firms' share in total manufacturing output s_{it}. We calculate W_{kt} for all firms operating in sector k in the sample for each year t. We then decompose the aggregate energy intensity into the unweighted aggregate energy intensity and the covariance between firms' shares of the entire industry's output and its energy intensity:

$$\underbrace{W_{kt} = \sum_i s_{ikt}\ lnEI_{ikt}}_{\substack{\text{Aggregate} \\ \text{energy intensity}}} = \underbrace{\overline{lnEI}_{kt}}_{\substack{\text{Unweighted average} \\ \text{energy intensity}}} + \underbrace{\sum_i (s_{ikt} - \overline{s}_{kt})\left(lnEI_{ikt} - \overline{lnEI}_{kt}\right)}_{Reallocation} \qquad (8)$$

where s_{ikt} 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, $lnEI_{ikt}$ is firm i's log(energy expenditure/real output), $\overline{lnEI}_{kt}$ is the average log(energy expenditure/real output) over all plants in the manufacturing sector.

Changes in the first term (unweighted average energy intensity) reflect firm-level changes in energy intensity. Changes in the second term (reallocation), 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.

Because of data constraints, we cannot measure W_{kt} and its two components for the entire population of manufacturing firms. Rather, we compute the three measures on our estimation sample used in the firm-level analysis. Because this sample includes only firms that are surveyed in EACEI, its composition changes over time. However, large firms are always sampled and small firms are representative of the population. Therefore, our measurement is a good approximation of what happens for the entire population.

Table 8 shows the logged energy intensity and its two components by 2-digit sectors. First, we observe that the weighted energy intensity is lower than the unweighted energy intensity is most sectors except furniture, paper, and chemicals. In other words, energy-efficient firms detain larger market shares than energy inefficient firms in 85% of the sectors. This is not surprising. Energy efficient firms have lower energy bills and therefore lower production costs.[40]

There is substantial heterogeneity between the different sectors. Output reallocation from inefficient to efficient firms is substantial in textiles, basic metals, non metallic minerals, and metal products. On the contrary, output reallocation towards efficient firms is very small in beverages, wood products, and electronics.

Table 8: Energy intensity and output reallocation between firms

Code	Sector	Weighted energy intensity	Unweighted energy intensity	Output reallocation
10	Food products	0.014	0.039	-0.025
11	Beverages	0.048	0.056	-0.008
13	Textiles	0.005	0.050	-0.045
14	Wearing apparel	0.005	0.015	-0.010
15	Leather	0.003	0.011	-0.009
16	Wood products	0.029	0.032	-0.003
17	Paper	0.064	0.057	0.007
20	Chemicals	0.102	0.068	0.034
21	Pharmaceuticals	0.008	0.024	-0.015
22	Plastic	0.013	0.031	-0.018
23	Non-metallic minerals	0.061	0.092	-0.031
24	Basic metals	0.035	0.069	-0.034
25	Metal products	0.002	0.028	-0.026
26	Electronics	0.009	0.011	-0.002
27	Electrical equipment	0.004	0.014	-0.010
28	Machinery	0.006	0.016	-0.010
29	Motor vehicles	0.007	0.020	-0.013
30	Other transport	0.007	0.018	-0.011
31	Furniture	0.026	0.026	0.000

Note: Logged value of energy intensity and its components as defined in equation (8) averaged over 2001-2015.

[40] Output reallocation is positive in furniture, paper, and chemicals because these sectors regroup industries that have large differences in terms of energy intensity. For instance, the paper sector includes the pulp and paper industry, energy intensive, as well as the publishing industry that is not energy intensive. Firms operating in energy intensive industries tend to be greater in size and capture a large part of the sector level market.

Table 9: Correlation between FEPI, aggregate energy intensity and aggregate job flow metrics

	Gross job creation rate			Gross job destruction rate			Net job creation rate		
Output reallocation towards energy inefficient firms	-0.101 (0.129)			0.068 (0.077)			-0.17 (0.113)		
Simple average energy intensity		-0.007 (0.012)			0.003 (0.006)			-0.009 (0.014)	
Weighted average energy intensity			-0.034 (0.037)			0.008 (0.007)			-0.042 (0.039)
Industry FE	X	X	X	X	X	X	X	X	X
Year dummies	X	X	X	X	X	X	X	X	X
Observations	666	666	666	666	666	666	666	666	666
Number of industries	61	61	61	61	61	61	61	61	61
Adjusted R^2	0.10	0.10	0.11	0.38	0.38	0.38	0.19	0.19	0.20

Note: Each column corresponds to a separate OLS regression. Regressors are logged. Robust standard errors clustered at the 3-digit NACE are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5. Quantifying the employment reallocation and emissions reduction

5.1. Contribution of the energy price variation to workers reallocation

What share of total employment variation in the manufacturing sector is driven by changes in the energy price? To quantify the contribution of the energy price variation to total employment, we proceed as follows. First, we compute for each sector *k* and each year *t* the employment in *t* if energy price did not change from what they were in *t – 1*:

$$\overline{EMP}_{kt} = exp\left(\ln EMP_{kt} - \hat{\beta}_k(Cost_{kt} - Cost_{kt-1})\right) \qquad (9)$$

where $Cost_{kt} - Cost_{kt-1}$ is the observed change in the log of average energy cost between *t - 1* and *t* and $\hat{\beta}_k$ are the sector specific elasticities reported in Table A.5.[41] Data on job reallocation between each pair of firms are not available to us. Therefore, we use the effect of the firm's own energy cost on gross reduction in the number of employees $\hat{\beta}_k$ as a proxy for job reallocation.[42] The variation in employment due to changes in the energy price is:

$$\Delta\overline{EMP}_{kt} = EMP_{kt} - \overline{EMP}_{kt} \qquad (10)$$

Note that $\Delta\overline{EMP}_{kt}$ can be positive if the energy cost decreases.

Finally, we compute the change in employment due to the energy price as the share of total employment as follows:

$$\varphi_{kt} = \frac{|\Delta\overline{EMP}_{kt}|}{EMP_{kt}}$$

Figure 9 shows the φ_{kt} for each sector averaged over 2005-2016.[43] We find that the change in employment due to energy price variation equals 0.25% of total employment on average. The contribution of the energy price changes varies greatly across industries. Variation in the energy price causes substantial worker reallocation in food products (0.73%), in basic metals (0.61%), and in wearing apparels (0.53%) but very little reallocation in pharmaceuticals (0.07%), paper (0.05%), and textiles (0.04%).

These differences are mainly due to the $\hat{\beta}_k$ we estimate because the industries face quite similar level of annual variation in the energy cost (5.8% on average with a 1.9% standard deviation). For instance, the energy cost varies by 5% annually for basic metals

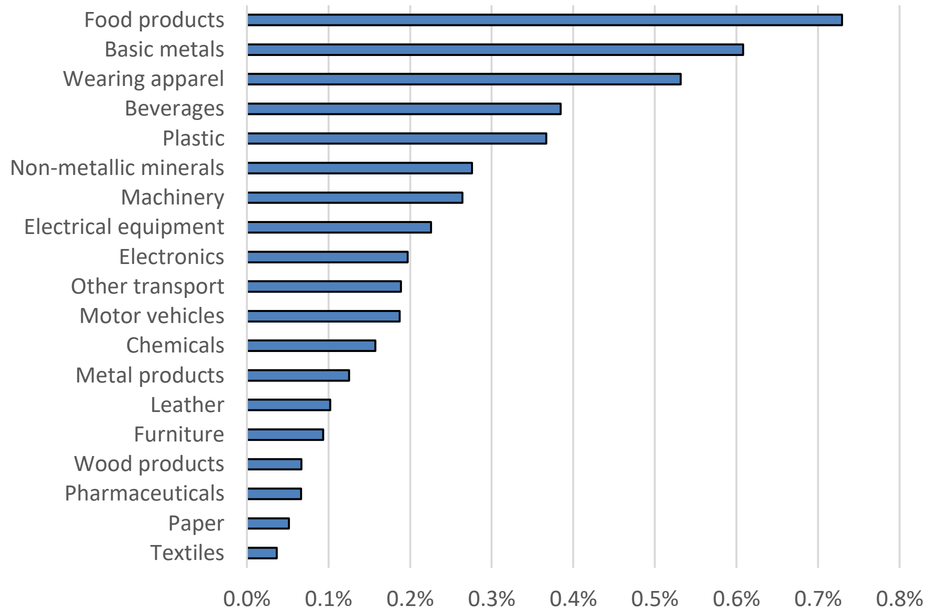
[41] The average increase in the energy cost is 167% between 2004 and 2016. We also consider elasticities that are not statistically different from zero.

[42] We use the same proxy for the simulation presented in section 5.3.

[43] We do not go back until 2001 because some sectors are not available in the list of plants of Insee before 2004.

and for machinery. Yet, the contribution of this energy price variation to labour reallocation for basic metal is more than twice the contribution found for machinery.

Figure 9: Labour reallocation due to energy price variation as a share of total employment



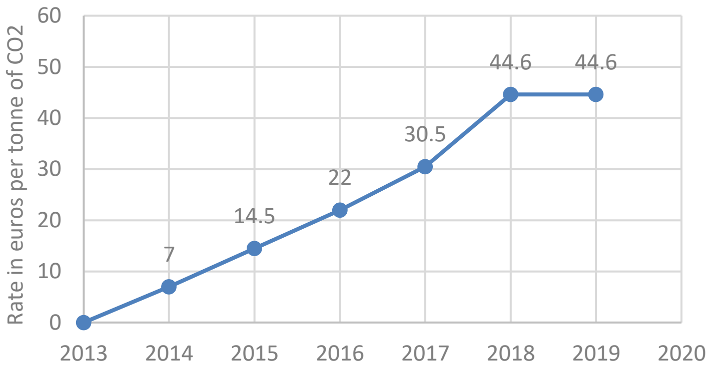
Note: average share of variation from 2005 to 2016.

5.2. Measuring the effect of the carbon tax from 2013 to 2018

In this section, we estimate ex-post the impact of the carbon tax on the French manufacturing sector's CO2 emissions and employment between 2014 and 2018.

The carbon tax was introduced in France in 2014 at 7 € per tonne of CO_2. Figure 10 shows the evolution of the legislation. Since its introduction, the carbon tax has progressively increased to reach 44.6 € per tonne of CO_2 in 2018. Because fuels have a different emission factor, the tax on CO_2 translates into different fuel specific carbon taxes.

Figure 10: The evolution of the French carbon tax



Note: the data come from article 266 quinquies B of the French customs law, the 2018 Finance Bill, and the 2019 Finance Bill.

For example, the carbon tax for natural gas at its 2018 level of 44.6 € per tonne of CO_2 corresponds to 8.45 € per MWh. However, there are two reduced rates designed to preserve the competitiveness of energy-intensive companies.[44] The first reduced rate, equal to 1.52 € per MWh, is intended for energy-intensive companies subject to the European Union Emissions Trading Scheme (EU ETS). The second reduced rate, equal to 1.60 € per MWh, is intended for energy-intensive companies subject to a risk of carbon leakage[45]. An energy-intensive company as defined in Article 17 of Directive 2003/96/EC is an enterprise whose energy purchases represent at least 3% of the value of production or whose annual energy taxes represent more than 0.5% of value added. Finally, energy-intensive companies subject to the EU-ETS or to a risk of carbon leakage are exempted to pay the carbon tax on heating oil and on butane/propane. Firms that are energy-intensive and part of the EU ETS represent 2.3% of the firms in our estimation sample whereas firms that are energy-intensive and subject to carbon leakage account for 10.1% of the firms in our estimation sample. These exemptions are not taken into account in this section because we use our estimated coefficients on aggregate carbon emissions and aggregate employment at the manufacturing sector level. Therefore, the magnitude of the effects of the carbon tax shown in Figure 11 are slightly overestimated. However, we account for tax exemptions and reduced rates when simulating job reallocations in section 5.3

To estimate the impact of the carbon tax on the French manufacturing sector, we build a counterfactual scenario for total employment and total carbon emissions in which there is no carbon tax. Counterfactual emissions are computed as

$$CO2_t^{notax} = exp\left(\ln CO2_t^{tax} - \hat{\beta}_1^{CO2}\left(\ln \mathrm{Cost}_t^{tax} - \ln \mathrm{Cost}_t^{notax}\right)\right)$$

Where $CO2_t^{tax}$ if the actual French manufacturing sector emissions at year t, $\hat{\beta}_1^{CO2}$ is the effect of the energy cost on carbon emissions estimated at -0.92 as reported in Table 1,

[44] In French, these firms are called “grande consommatrice d’énergie”.

[45] The list of sectors subject to a risk of carbon leakage is established by Decision No 2014/746/EU of 27 October 2014.

Cost_t^{tax} is the energy cost when the carbon tax is included, and Cost_t^{notax} is the energy cost when the carbon tax is excluded.

Similarly, counterfactual employment is computed as

$$Jobs_t^{notax} = exp\left(\ln Jobs_t^{tax} - \widehat{\beta}_1^{Jobs}\left(\ln \text{Cost}_t^{tax} - \ln \text{Cost}_t^{notax}\right)\right)$$

Where $\hat{\beta}_1^{Jobs}$ is the effect of the energy cost on total jobs estimated at 0.114 as reported in Table 7.

We compute Cost_t^{notax} as a weighted average of electricity, natural gas, heating oil, and butane propane price excluding the carbon tax.[46] Each fuel weight equals the average share of the fuel in total energy use in the manufacturing sector.[47] We compute the Cost_t^{tax} by adding the carbon tax to each fuel price.[48] Data on $CO2_t^{tax}$ and $Jobs_t^{tax}$ come from Insee.[49]

Figure 11 plots the carbon tax on the left axis (green line) and the impacts of the French carbon tax on the French manufacturing sector's jobs (purple line) and carbon emissions (red line) on the right axis. When the carbon tax was introduced in 2014 at 7 euros per tonne, it reduced carbon emissions by 1%. In 2018, the carbon tax decreased carbon emissions by 5% or 3.6 Mt of CO_2. The effect on employment is much smaller in magnitude and positive at +0.8% in 2018. Figure 11 also plots the difference between the second carbon budget for the manufacturing industry for 2019-2023 and the emissions in the scenario with no tax (orange line). This difference increases over time because emissions shrink due to factors other than the carbon tax. Until 2016, the carbon tax was not high enough to meet the second carbon budget. Therefore, we can conclude that the French carbon tax allowed to reach this objective before 2019 with no negative effect on total manufacturing employment.

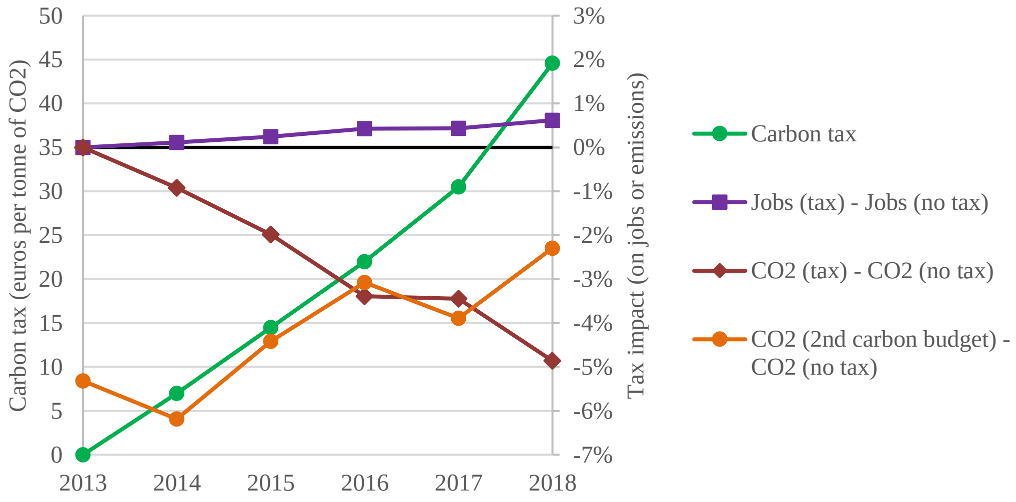
[46] We use data on fuel price from EACEI time series SL_T1 available for download on https://www.insee.fr/fr/statistiques/3702790?sommaire=3702794. We input 2018 prices using the prices of 2017. We convert all prices to euros per MWh using the conversion factors of Ademe.

[47] As reported in the data section, electricity accounts for 58% of the energy use, natural gas for 28%, heating oil for 6%, and butane propane for 4%. The sum of these weights equals 96% so we normalise the weight in order to obtain a sum of 100%.

[48] The carbon tax data come from article 266 quinquies B of the French customs law, the 2018 Finance Bill, and the 2019 Finance Bill.

[49] Data are available on https://www.insee.fr/fr/statistiques/2015759 for carbon emissions and on https://www.insee.fr/fr/metadonnees/source/serie/s1283/bases-donnees-ligne for employment.

Figure 11: The effect of the carbon tax on the French manufacturing sector



Note: Authors' calculation using estimated coefficient for equation (1) and equation (7) and data on aggregate carbon emissions and employment of the French manufacturing sector from Insee.

5.3. Quantifying the short-run effects of a potential carbon tax increase

In this section, we simulate the impact of a further carbon tax increase on firms' CO_2 emissions and employment in the short run. This simulation does not include general equilibrium effects as it is based on the firm-level analysis. In other words, the magnitude reported in this section does not represent the total effect of the carbon tax on the industry but rather what happens in the short run to the average firm in different sectors before output, labour, and emissions reallocations take place.

We consider a scenario where the carbon tax increases from its 2018 rate of 44.6 € per tonne of CO_2 to a rate of 86.2 € per tonne of CO_2. In this scenario, the reduced tax rates for natural gas do change in the same proportion as the full tax rate. The first reduced rate changes from 1.52 € to 2.88 € per MWh and the second reduced rate changes from 1.60 € to 3.03 € per MWh. First, we use firm-level data of 2012-2016 to compute the change in average energy cost due to the tax increase.[50] Second, we map the average energy cost change into emissions reduction and employment reduction using our sector-specific elasticities estimates reported in Table A.5.

Table 10 shows the results for 19 different sectors in our estimation sample composed of 4,055 firms. Under the 86.2 € per tonne of CO_2 scenario, the average energy cost rises by 4.3% on average. Unsurprisingly, there is substantial heterogeneity across industries. The increase in energy cost is at least equal to 5% for other transport, machinery, and textiles whereas it is below 3% for wood products, plastics, and electronics. The average firm reduces its emissions by 41 tonnes of CO_2 and reallocate employment 0.4 full time equivalent (FTE). The largest emissions declines are over 125 tonnes of CO_2 per firm and take place in the basic metal sector. The largest average employment reallocation

[50] We take the last year available for each firm. Going back to 2012 allows to recover a reasonable number of firms, typically small, that are not sample every year in the energy survey.

per firm, 1.3 FTE, also occurs in the other transport sector. Note that these industry-specific simple averages are driven by large firms that are over-represented in our sample.[51] Consequently, these reported averages tend to overestimate the reduction in emissions and reallocation in employment.

To go further, we provide an order of magnitude of the effect at the manufacturing sector level. To do that, we need to assume that the small 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 in emissions, we multiply the sector-specific marginal effects reported in Table 10 by the total number of firms operating in these industries.[52] For each industry, we compute the average percentage of employment effect using the energy cost increase on the 2012-2016 data and the employment elasticity of Table A.5. We multiply the industry-specific percentage change with the firm's actual number of employees. These firm-level changes are then summed to estimate the total change the 19 industries. The results are reported in Table 11.

We find that increasing the carbon tax from 44.6 € to 86.2 € per tonne reduces CO_2 emissions by 6.2 million tonnes and leads to a reallocation of 6,357 FTE, representing respectively 8.7% of total emissions and 0.24% of the workforce of the 19 industries covered in this study.[53] In relative terms, the reallocation of labour is the most important in the basic metal, food product, beverages, wearing apparel, plastic, and machinery where it represents at least 0.3% of the workforce in these industries. In absolute terms, the food products industry contributes the most to carbon emission reduction with 2.8 Mt of CO_2 followed by non-metallic minerals (757 kt of CO_2), metal products (429 kt of CO_2), and beverages (402 kt of CO_2).

Note that these figures are only orders of magnitude and not accurate estimates. General equilibrium effects such as the entry of new firms in the market due to the energy price increase are not modelled in this micro-econometric model.

Why would a 100% increase in the carbon tax have such a small effect on total CO_2 emissions and employment? The main answer is that the induced energy cost increase is rather small ranging from 2.1% to 6.8%. The raise in energy cost is limited for two reasons. First, fossil fuel represents only 36% of total energy use on average. Second, the share of fossil fuel consumed by firms having the reduced carbon tax rate is 16.4% on average but can go well beyond 30% in some sectors like textiles, wood products, and basic metals particularly exposed to foreign competition.[54]

In the scenario with additional measures (AMS) of the French national low-carbon strategy, the first carbon budget for the manufacturing industry for 2015-2018 equals 80 Mt of CO_2 and the second carbon budget for 2019-2023 equals 72 Mt of CO_2. Carbon emissions will have to decrease by 4 Mt of CO_2 in comparison to 2013 emissions to meet the second carbon budget. Our simulation shows that increasing the full carbon tax rate from 44.6 € to 86.2 € per tonne of CO_2 and the reduced tax rate for natural gas in the same proportion decrease carbon emissions by 6.2 Mt of CO_2. In section 5.2, we estimate

[51] Because they are sample more regularly in the EACEI survey.

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

[53] We cover sectors representing 83% of the French manufacturing sector emissions and 97% of its workforce.

[54] See Table 10 for the statistics by sector.

that the 44.6 € per tonne of CO_2 carbon tax has already almost fulfilled the second carbon budget by reducing emissions in 2018 by 3.6 Mt of CO_2.

The abatement of the remaining 0.4 Mt CO_2 will be probably achieved by further increase in the EU-ETS allowance price which kept increasing since the beginning of 2018 from 7 € to 25 € in June 2019.

Table 10: Carbon tax increase on emissions and employment for firms in our sample

Industry code	Industry label	Number of firms	Fossil fuel (% of energy use)	Exempted fossil fuel use (% of total sector)	% increase in energy cost	CO_2 emissions reduction		Employment reallocation	
						(t CO_2 / firm)	(%)	(FTE per firm)	(%)
10	Food products	483	35.3	1.8	4.89	46.47	1.44	0.78	0.35
11	Beverages	55	33.9	13.5	4.38	110.16	3.44	0.93	0.32
13	Textiles	153	45.4	63.5	5.02	21.08	2.03	0.03	0.03
14	Wearing apparel	40	43.2	16.4	4.76	22.11	2.70	0.69	0.29
15	Leather	34	41.2	7.4	4.46	3.92	1.10	0.20	0.06
16	Wood products	188	17.2	67.6	2.06	21.16	1.28	0.02	0.02
17	Paper	257	36.6	44.1	3.89	71.57	1.91	0.05	0.04
20	Chemicals	322	43.9	9.9	4.80	88.01	1.50	0.27	0.16
21	Pharmaceuticals	80	42.3	10.8	4.75	19.57	0.31	0.55	0.09
22	Plastic	448	21.8	10.5	2.81	16.00	0.64	0.57	0.21
23	Non-metallic minerals	328	45.1	11.3	3.97	71.66	1.17	0.29	0.21
24	Basic metals	205	41.8	34.0	3.80	124.74	1.59	0.91	0.44
25	Metal products	753	35.8	6.3	4.70	18.54	1.11	0.16	0.12
26	Electronics	50	17.9	3.5	2.05	9.55	0.78	0.49	0.09
27	Electrical equipment	167	38.4	19.2	4.64	25.15	1.45	0.72	0.22
28	Machinery	230	45.2	9.5	5.83	22.48	1.64	0.88	0.30
29	Motor vehicles	183	30.9	2.4	3.98	13.06	0.65	0.55	0.16
30	Other transport	16	51.4	0	6.77	-147.60	-2.61	1.33	0.14
31	Furniture	63	36.3	0	4.89	19.40	2.22	0.08	0.05
	Weighted average	4,055	35.9	16.4	4.26	41.02	1.30	0.43	0.19

Note: The quantities reported in this table are estimated using the absolute value of the coefficients reported in Table A.5. and firms' specific simulated increase in average energy cost due to the carbon tax increase. In this scenario, the carbon tax increases from 44.6 € per tonne of CO_2 to a rate of 86.2 € per tonne of CO_2.

Table 11: Extrapolated effect of a carbon tax increase on CO2 emissions and employment

Sector code	Sector label	Number of firms	Number of employees	Employment reallocation (FTE)	Reduction in emissions (kt CO_2)
10	Food products	59,421	581,509	2,451	2,761
11	Beverages	3,650	44,526	156	402
13	Textiles	6,435	46,801	17	136
14	Wearing apparel	16,740	54,735	187	370
15	Leather	3,029	32,291	25	12
16	Wood products	11,673	71,865	22	247
17	Paper	1,919	66,483	25	137
20	Chemicals	3,606	143,048	286	317
21	Pharmaceuticals	464	75,878	73	9
22	Plastic	4,520	169,466	426	72
23	Non-metallic minerals	10,558	113,327	265	757
24	Basic metals	1,247	92,361	431	156
25	Metal products	23,122	315,629	490	429
26	Electronics	3,672	133,473	119	35
27	Electrical equipment	2,952	112,815	251	74
28	Machinery	6,298	183,118	514	142
29	Motor vehicles	2,242	206,937	350	29
30	Other transport	1,289	148,656	248	-190
31	Furniture	13,748	53,754	21	267
	Total	176,585	2,646,672	6,357	6,162

Note: The quantities reported in this table are extrapolated based on Table A.5. and the employment structure of the French manufacturing sector. Note that all quantities reported are total and not average. Sectors with coefficient that are not statistically significant are also included in the calculation.

6. Conclusions and possible future work

This study provides new evidence on the effect of energy price changes on firm-level environmental and economic performance using a unique dataset utilising micro-level information from French manufacturing firms. The study addresses the endogeneity of firm-level energy costs by using an Instrumental Variable method based on sector-level exogenous variation in energy prices.

The results suggest that a 10% increase in energy costs results in a decline in energy use by 6% and a decline in carbon emissions of 9%. When we account for between firms' adjustments in our industry-level analysis, we find that the energy cost increase has no statistically significant effect on net employment. We show that this is because output and workers are reallocated from energy-intensive firms to energy-efficient firms. This result at the macro-level is consistent with our firm-level analysis where we find that employment can decline as energy price increases for some medium-sized and large firms. However, the change in employment (2.6-5.6%) is far smaller than the decrease in CO2 emissions, suggesting that affected firms manage to partly reduce their energy intensity other than through reductions in the size of the workforce. In contrast to large firms, surviving small firms (which represent 99% of French manufacturing firms and 28% of the workforce) do not reduce employment when the energy price increases.[55]

These results allow us to conclude that climate policies (such as carbon taxes) that increase the energy cost generate employment reallocation between firms and industries, but do not reduce total employment. These reallocations are relatively important in the industries of basic metals, food products, beverages, wearing apparels, plastics, and machinery.[56] Because these reallocation have redistributive impications and generate costs for laid-off workers, these results call for complementary labour policies that ease these between-firms adjustments in employment.

We find that the 44.6 € per tonne of CO_2 carbon tax decreased emissions by 3.6 Mt in 2018. We find that if the French carbon tax changes from its actual rate of 44.6 € to 86.2 € per tonne of CO_2, then emission of the manufacturing sector would further decrease by 6.2Mt of CO_2. This reduction is consistent with the objective of the French low-carbon strategy which is to reduce the carbon budget for the manufacturing industry from 80 Mt of CO_2 in 2015-2018 to 72 Mt of CO_2 in 2019-2023. The abatement of the remaining 0.4 Mt CO_2 will be probably achieved by further increase in the EU-ETS allowance price which kept increasing since the beginning of 2018.

Furthermore, we find some evidence that an increase in the energy price modifies the technology produced and used by the firms. Large firms innovate more (as measured by patent filings) while all firms invest more in end-of-pipe pollution abatement technologies.

[55] However, it is possible that a portion of the small firms exit the market in response to higher energy cost but this is something we cannot test.

[56] In terms of reallocation as share of total employment. There is significant reallocation in the food products industry mainly because this is the largest industry in France.

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 analyse 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, the absence of data on output quantity prevents us from analysing the effect of the energy price on total factor productivity and output prices.
- Third, more data on emissions other pollutants would be necessary to understand the net effect of energy taxation on total pollution.
- Finally, we do not explore offshoring, which is a potentially important adjustment mechanism for firms faced with an energy price increase.

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Annex A. Additional tables and figures

Summary statistics

Table A.1. Summary statistics for the firm-level sample

Variable	Obs.	Mean	Std. Dev.	Min	Max
Family patent stock	29,683	-0.26	1.92	-6.49	7.01
Energy use	48,309	5.88	1.70	-6.31	13.73
Electricity use	48,300	5.24	1.64	-6.31	12.36
Fossil fuel use	42,963	5.00	1.93	-2.79	13.67
CO_2 emissions	48,309	13.10	1.87	0.05	21.60
Workers	48,309	4.70	1.06	0.00	10.15
Real output	48,309	9.86	1.34	3.05	16.53
Investment	38,932	6.02	1.81	-0.64	13.54
Real energy intensity	48,309	-3.98	1.17	-14.63	1.63
Energy use per worker	48,309	1.18	1.23	-9.65	8.17
Energy use per material	48,309	-2.86	1.45	-13.81	9.55
Energy use per capital	48,309	-2.85	1.20	-13.11	4.28
Electricity / fossil	42,954	0.34	1.39	-5.39	10.30
Average energy cost	48,309	-0.44	0.34	-5.96	5.84
Firm age in years	48,309	2.54	2.67	0.00	11.50
ETS (0/1)	48,309	0.02	0.13	0.00	1.00
Energy price index (FEPI)	48,309	-0.43	0.29	-1.53	0.55
Small firms (> 20 & < 50 employees)	48,309	0.30	0.46	0.00	1.00
Large firms (> 250 employees)	48,309	0.21	0.41	0.00	1.00
Year	48,309	2008.84	4.36	2001	2016

Note: The unit of observation is the firm. All variables are logged except plant age and the ETS dummy.

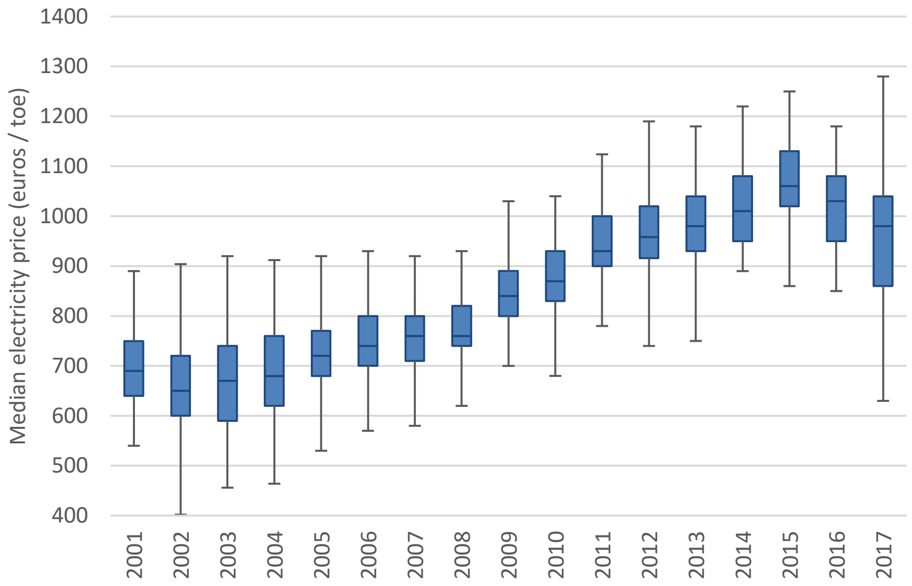
Table A.2. Summary statistics for the plant-level sample

Variable	Obs.	Mean	Std. Dev.	Min	Max
Investment to reduce all kind of pollution	18,135	3.57	1.72	-2.34	10.28
Investment to reduce water pollution	18,135	2.47	1.89	-4.30	9.83
Investment to reduce air pollution	14,501	2.50	1.99	-4.43	9.94
Investment to reduce waste pollution	16,953	1.95	1.68	-5.23	9.33
Investment to reduce soil pollution	15,198	1.94	1.95	-4.70	9.54
Energy price index (FEPI)	18,135	-0.59	0.30	-1.73	0.25
Plant age in years	18,135	30.33	35.83	0	114.00
ETS (0/1)	18,135	0.05	0.21	0	1

Note: The unit of observation is the plant. All variables are logged except plant age and the ETS dummy.

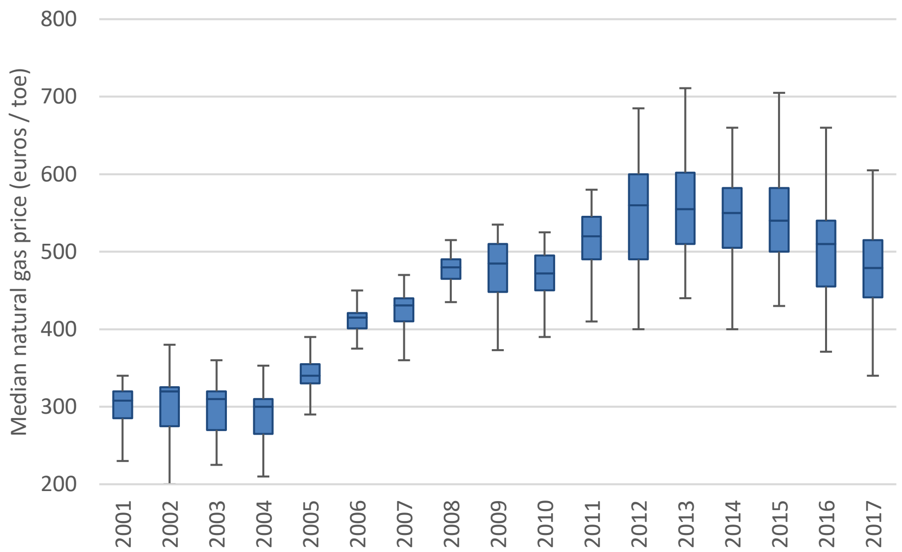
Variation in fuel prices between industries over time

Figure A.1. Distribution of median electricity price over time



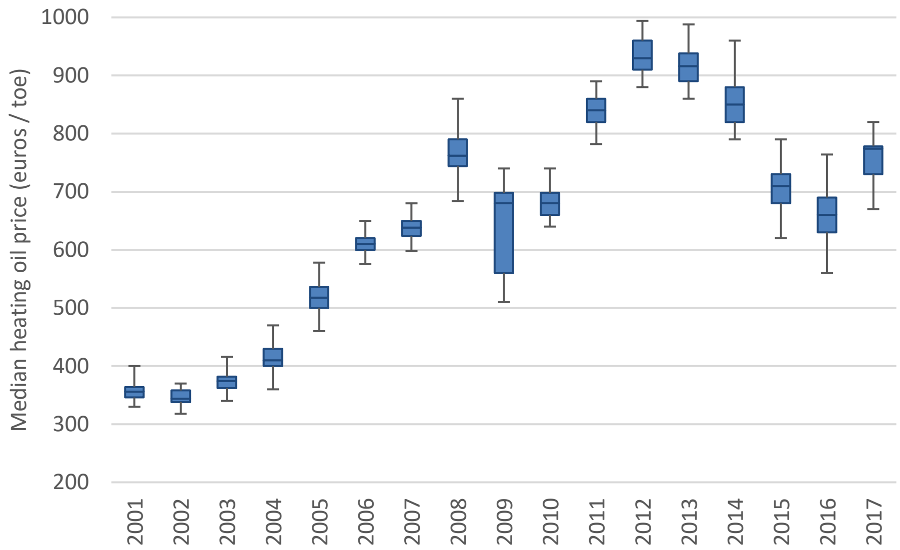
Note: median computed for each 3-digit industry.

Figure A.2. Distribution of median natural gas price over time



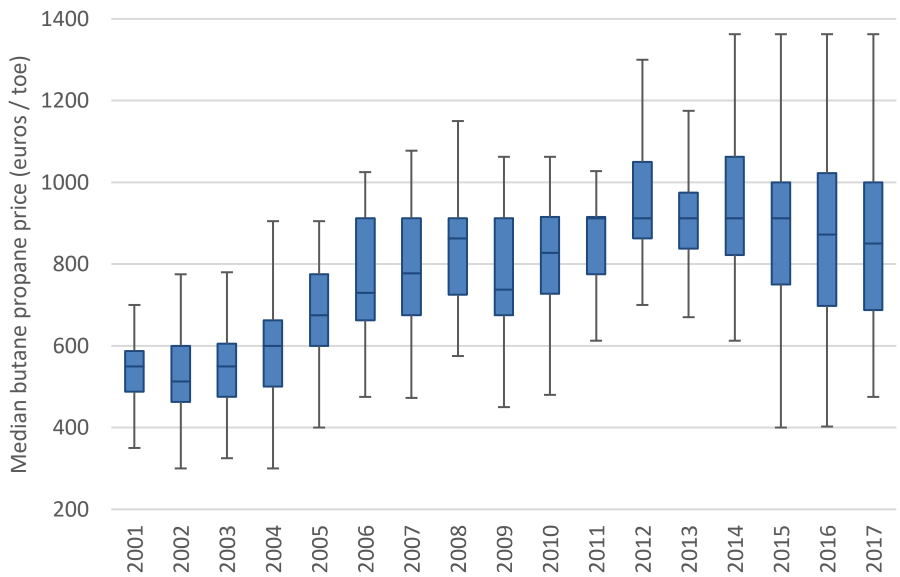
Note: median computed for each 3-digit industry.

Figure A.3. Distribution of median heating oil over time



Note: median computed for each 3-digit industry.

Figure A.4. Distribution of median butane propane price over time



Note: median computed for each 3-digit industry.

Within sector variation in fuel prices

Table A.3. Within sector variation in fuel prices

Sector code	Sector label	Electricity			Natural gas			Heating oil			Butane propane		
		Mean	Std. Dev.	CV (%)	Mean	Std. Dev.	CV (%)	Mean	Std. Dev.	CV (%)	Mean	Std. Dev.	CV (%)
10	Food products	957	195	20%	491	138	28%	718	238	33%	649	417	64%
11	Beverages	1,046	305	29%	518	117	23%	717	195	27%	717	408	57%
13	Textiles	1,112	437	39%	526	150	29%	661	108	16%	951	387	41%
14	Wearing apparel	1,243	346	28%	619	169	27%	806	497	62%	894	646	72%
15	Leather	1,195	223	19%	558	128	23%	591	72	12%	949	553	58%
16	Wood products	1,155	268	23%	579	176	31%	726	226	31%	1,005	830	83%
17	Paper	1,013	255	25%	505	167	33%	700	184	26%	894	357	40%
20	Chemicals	1,024	239	23%	502	212	42%	764	537	70%	1,000	868	87%
21	Pharmaceuticals	923	120	13%	472	87	19%	790	314	40%	1,211	436	36%
22	Plastic	993	221	22%	603	192	32%	721	258	36%	980	514	52%
23	Non-metallic minerals	1,058	302	29%	578	1,082	187%	705	189	27%	926	530	57%
24	Basic metals	890	224	25%	441	120	27%	737	226	31%	979	711	73%
25	Metal products	1,107	274	25%	580	205	35%	779	736	94%	942	557	59%
26	Electronics	1,011	200	20%	592	199	34%	744	230	31%	1,360	519	38%
27	Electrical equipment	1,065	220	21%	531	121	23%	775	357	46%	1,004	586	58%
28	Machinery	1,059	221	21%	544	120	22%	767	263	34%	985	496	50%
29	Motor vehicles	953	195	20%	521	132	25%	863	559	65%	846	391	46%
30	Other transport	1,095	374	34%	552	165	30%	755	278	37%	992	463	47%
31	Furniture	1,090	225	21%	544	107	20%	591	91	15%	653	202	31%
	Mean of all sectors	1,052	255	24%	540	199	36%	732	293	39%	944	519	55%

Note: Author's calculation based on the year 2016. All value are expressed in euros per tonne of oil equivalent.

Summary of within and between industries variation in fuel prices

Table A.4. Distribution of the median price at the 3-digits industry level

Fuel	Obs.	Mean	Std. Dev.	p10	p90	CV (%)	Increase (%)
Electricity	67	1,013	113	879	1,138	11%	47%
Natural gas	67	506	70	416	578	14%	67%
Heating oil	67	677	109	598	766	16%	88%
Butane propane	67	871	269	565	1,166	31%	59%

Note: The increase equals the ratio between the fuel price in 2016 and the fuel price in 2001 minus 1.

Sector specific effects of energy price variation on carbon emissions and number of workers

Table A.5. CO_2 emissions and workers elasticities by sector

Sector code	Sector label	Number of firms	Average energy intensity (toe / thousand euros)	Energy as % of turnover	CO_2 emissions		Workers	
					Coeff.	Std. Err.	Coeff.	Std. Err.
10	Food products	1,282	36	1.7%	-0.309***	0.098	-0.075*	0.042
11	Beverages	139	27	1.2%	-0.833*	0.434	0.075	0.121
13	Textiles	309	47	2.7%	-0.432***	0.148	-0.007	0.033
14	Wearing apparel	161	15	1.0%	-0.603***	0.189	-0.063	0.051
15	Leather	103	11	0.7%	-0.256	0.221	0.015	0.082
16	Wood products	370	33	1.9%	-0.651***	0.129	-0.012	0.048
17	Paper	517	55	2.4%	-0.517***	0.112	-0.011	0.027
20	Chemicals	521	67	2.8%	-0.329**	0.13	-0.034	0.026
21	Pharmaceuticals	81	24	1.9%	-0.068	0.194	-0.02	0.06
22	Plastic	891	31	2.0%	-0.236***	0.075	-0.078***	0.026
23	Non-metallic minerals	541	87	4.0%	-0.310***	0.112	-0.055**	0.023
24	Basic metals	314	69	3.4%	-0.441***	0.165	-0.122**	0.049
25	Metal products	1,402	28	1.7%	-0.247***	0.072	-0.027*	0.015
26	Electronics	151	12	0.9%	-0.391**	0.197	0.043	0.053
27	Electrical equipment	278	14	0.8%	-0.327**	0.154	-0.049	0.046
28	Machinery	435	15	0.9%	-0.296***	0.104	0.053	0.032
29	Motor vehicles	287	18	1.3%	-0.170	0.150	-0.041	0.039
30	Other transport	35	20	1.2%	0.395	0.300	0.022	0.098
31	Furniture	182	21	1.4%	-0.481***	0.140	-0.01	0.052

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Annex B. Testing for weak instruments

The consistency of the above estimations lies on the strength of our instrumental variable. The estimated Kleibergeen Paap statistic is statistically different from zero in all regressions.[57] Thus, we reject the null hypothesis that FEPI is a weak instrumental variable. Table B.5. shows the first-stage estimation results. For the first stage estimation of model (1), the coefficient of FEPI equals 0.583 and is statistically different from 0 at the 1% level. In addition, the F-statistic equals 173 which is way above 10 that is the usual threshold used. Similarly, the instrumental variables for the estimation of model (2) are strong.

Table B.1. First-stage regressions

	Model (1)	Model (2)		
	ln(avg. energy cost)	ln(avg. energy cost)	ln(avg. energy cost) x Small (0/1)	ln(avg. energy cost) x Large (0/1)
FEPI	0.583***	0.567***	-0.075***	-0.115***
	(0.027)	(0.028)	(0.016)	(0.012)
FEPI x Small (0/1)		-0.019	0.904***	0.000
		(0.021)	(0.018)	(0.002)
FEPI x Large (0/1)		0.083***	0.003*	0.986***
		(0.013)	(0.002)	(0.010)
Firm age in years	0.000	-0.001	0.000	-0.001
	(0.002)	(0.002)	(0.001)	(0.001)
ETS (0/1)	0.052***	0.042***	0.005	0.020***
	(0.012)	(0.012)	(0.004)	(0.007)
Firm FE	X	X	X	X
Industry x Year dummies	X	X	X	X
Observations	45,903	45,903	45,903	45,903
Number of firms	8,002	8,002	8,002	8,002
F-statistic	173	100	427	1,776

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

[57] The Kleibergeen Paap statistic is a version of the first stage F-statistic that is robust to heteroscedasticity.

Annex C. Robustness checks

OLS results

Table C.1. OLS estimates for environmental and economic performance

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.223***	-0.091***	-0.365***	-0.343***	-0.037***	-0.042***	-0.080**
	(0.025)	(0.020)	(0.044)	(0.035)	(0.008)	(0.009)	(0.036)
Firm age in years	-0.030***	-0.038***	-0.013	-0.023***	-0.032***	-0.033***	0.004
	(0.007)	(0.007)	(0.009)	(0.007)	(0.004)	(0.004)	(0.013)
ETS (0/1)	-0.011	-0.043	0.06	0.016	0.045*	0.072**	0.006
	(0.037)	(0.035)	(0.061)	(0.044)	(0.026)	(0.028)	(0.071)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	45,903	45,893	40,788	45,903	45,903	45,903	36,327
Number of firms	8,002	7,999	7,048	8,002	8,002	8,002	7,168

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables are logged. All columns are estimated with the OLS estimator. Average energy cost equals the log of the ratio between energy expenditure and energy use. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Table C.2. OLS estimates for energy intensity and input substitution

	Real energy intensity	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost)	-0.181***	-0.185***	-0.206***	-0.186***	0.279***
	(0.024)	(0.023)	(0.028)	(0.024)	(0.044)
Firm age in years	0.003	0.003	0.000	0.001	-0.016*
	(0.006)	(0.007)	(0.008)	(0.007)	(0.009)
ETS (0/1)	-0.084**	-0.057*	-0.106***	-0.051	-0.096*
	(0.036)	(0.034)	(0.039)	(0.042)	(0.054)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	45,903	45,903	45,903	45,903	40,778
Number of firms	8,002	8,002	8,002	8,002	7,045

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables are logged. All columns are estimated with the OLS estimator. Average energy cost equals the log of the ratio between energy expenditure and energy use. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Exploring heterogeneities based on firm size

Table C.3. Heterogeneous effects on environmental performance and economic performance

	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.721***	-0.374***	-0.840***	-0.989***	-0.455***	-0.189**	-0.933***
	(0.118)	(0.117)	(0.180)	(0.156)	(0.066)	(0.075)	(0.289)
ln(avg. energy cost) x SME (0/1)	0.268***	0.338***	0.210***	0.224***	0.338***	0.206***	0.375***
	(0.049)	(0.052)	(0.064)	(0.056)	(0.036)	(0.043)	(0.101)
Firm age in years	-0.030***	-0.036***	-0.019**	-0.026***	-0.034***	-0.033***	-0.002
	(0.007)	(0.008)	(0.008)	(0.008)	(0.004)	(0.004)	(0.014)
ETS (0/1)	0.045	0.001	0.112*	0.081*	0.091***	0.097***	0.108
	(0.036)	(0.034)	(0.058)	(0.042)	(0.024)	(0.028)	(0.079)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	45,893	45,883	40,778	45,893	45,893	45,893	36,317
Number of firms	8,000	7,997	7,046	8,000	8,000	8,000	7,166
KP LM statistic	285	284	243	285	285	285	230

Note: Robust standard errors clustered at the firm level in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. All outcome variables 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 SME dummy equals 1 when the pre-sample number of workers of the firms is lower than 250. The instrumental variables for the average energy cost and the interactions terms are the Fixed weight Energy Price Index (FEPI) and the FEPI interacted with the SME dummy. The first-stage regressions are available upon request. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Contemporaneous effect of energy price variation

Table C.4. Results on environmental and economic performance when regressors are not lagged

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.941***	-0.088	-1.326***	-1.754***	-0.171***	-0.113**	0.002
	(0.084)	(0.090)	(0.143)	(0.105)	(0.051)	(0.053)	(0.179)
Firm age in years	-0.031***	-0.039***	-0.015*	-0.020***	-0.030***	-0.032***	-0.013
	(0.006)	(0.006)	(0.008)	(0.006)	(0.004)	(0.004)	(0.010)
ETS (0/1)	-0.012	-0.055	0.029	0.046	0.063**	0.069**	0.005
	(0.037)	(0.037)	(0.052)	(0.042)	(0.028)	(0.029)	(0.067)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	66,742	66,719	57,183	66,742	66,742	66,742	54,464
Number of firms	11,214	11,211	9,569	11,214	11,214	11,214	10,366
KP LM statistic	651	653	461	651	651	651	601

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 available upon request. Regressors are not lagged. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Table C.5. Results on energy intensity and input substitution when regressors are not lagged

	Real energy intensity	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost)	-0.827***	-0.769***	-0.803***	-0.895***	1.509***
	(0.086)	(0.084)	(0.110)	(0.094)	(0.154)
Firm age in years	0.002	-0.001	0.000	0.007	-0.017**
	(0.005)	(0.006)	(0.007)	(0.006)	(0.008)
ETS (0/1)	-0.080**	-0.074**	-0.110***	-0.052	-0.096**
	(0.036)	(0.035)	(0.037)	(0.044)	(0.045)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	66,742	66,742	66,742	66,742	57,162
Number of firms	11,214	11,214	11,214	11,214	9,566
KP LM statistic	651	651	651	651	461

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 available upon request. Regressors are not lagged. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Sensitivity analysis for the merge between firm level data and plant level data

Table C.6. Energy price effect on environmental performance and economic performance when the employment threshold is 100%

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.655***	-0.187*	-0.796***	-1.006***	-0.208***	-0.121	-0.634**
	(0.114)	(0.113)	(0.180)	(0.148)	(0.069)	(0.081)	(0.278)
Firm age in years	-0.029***	-0.041***	0.002	-0.018**	-0.033***	-0.031***	-0.007
	(0.008)	(0.008)	(0.011)	(0.008)	(0.006)	(0.005)	(0.016)
ETS (0/1)	0.061	-0.015	0.163**	0.113**	0.073***	0.090***	0.035
	(0.043)	(0.041)	(0.072)	(0.050)	(0.028)	(0.032)	(0.093)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	40,084	40,075	35,256	40,084	40,084	40,084	31,594
Number of firms	7,364	7,361	6,441	7,364	7,364	7,364	6,553
KP LM statistic	324	323	279	324	324	324	251

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 are available upon request. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Table C.7. Energy price effect on environmental performance and economic performance when the employment threshold is 85%

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.584***	-0.161	-0.618***	-0.896***	-0.217***	-0.045	-0.322
	(0.108)	(0.105)	(0.165)	(0.139)	(0.063)	(0.072)	(0.249)
Firm age in years	-0.032***	-0.038***	-0.017**	-0.026***	-0.033***	-0.032***	0.002
	(0.006)	(0.006)	(0.008)	(0.007)	(0.004)	(0.004)	(0.012)
ETS (0/1)	0.026	-0.025	0.087	0.070*	0.075***	0.079***	0.037
	(0.036)	(0.035)	(0.058)	(0.041)	(0.026)	(0.028)	(0.072)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	47,509	47,499	42,216	47,509	47,509	47,509	37,612
Number of firms	8,206	8,203	7,223	8,206	8,206	8,206	7,361
KP LM statistic	417	416	358	417	417	417	327

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 are available upon request. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Dynamic effects of energy price variation

Table C.8. Dynamic effects of energy price on environmental performance and economic performance

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost) t	0.005	-0.03	-0.29	-0.059	-0.069	0.002	0.088
	(0.166)	(0.149)	(0.241)	(0.219)	(0.067)	(0.091)	(0.466)
ln(avg. energy cost) t - 1	-0.112	-0.123	0.029	-0.111	-0.033	0.205**	0.011
	(0.182)	(0.154)	(0.244)	(0.241)	(0.063)	(0.084)	(0.510)
ln(avg. energy cost) t - 2	-0.472***	-0.017	-0.578**	-0.752***	-0.164**	-0.249***	-0.321
	(0.155)	(0.144)	(0.229)	(0.199)	(0.078)	(0.096)	(0.423)
Firm age in years t	-0.020**	-0.022***	-0.018	-0.014	-0.016***	-0.024***	-0.031**
	(0.008)	(0.006)	(0.011)	(0.010)	(0.005)	(0.004)	(0.016)
Firm age in years t - 1	-0.008	-0.015**	0.003	-0.005	-0.015***	-0.007**	0.027
	(0.006)	(0.007)	(0.009)	(0.007)	(0.004)	(0.004)	(0.018)
Firm age in years t - 2	-0.016**	-0.020***	-0.009	-0.014*	-0.010***	-0.012***	0.007
	(0.007)	(0.007)	(0.008)	(0.008)	(0.004)	(0.004)	(0.016)
ETS t	-0.046	0.003	-0.071	-0.064	0.034	0.025	-0.014
	(0.049)	(0.044)	(0.063)	(0.054)	(0.029)	(0.022)	(0.129)
ETS t - 1	0.083**	0.029	0.167***	0.121**	0.029	0.034*	0.047
	(0.042)	(0.038)	(0.054)	(0.047)	(0.030)	(0.018)	(0.123)
ETS t - 2	-0.013	-0.079	0.013	0.015	0.02	0.036	-0.006
	(0.065)	(0.057)	(0.079)	(0.070)	(0.026)	(0.027)	(0.090)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	33,980	33,976	30,838	33,980	33,980	33,980	26,325
Number of firms	6,206	6,205	5,603	6,206	6,206	6,206	5,491
KP LM statistic	73	73	68	73	73	73	64
Long run effect	-0.578***	-0.170	-0.840***	-0.922***	-0.266**	-0.042	-0.222
	(0.171)	(0.163)	(0.261)	(0.213)	(0.103)	(0.124)	(0.451)

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 are available in Table C.10. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption. The long run effect equals the sum of the coefficients of the logged average energy cost.

Table C.9. Dynamic effects of energy price on input substitution

	Real energy intensity	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost) t	0.003	0.074	0.131	-0.166	0.236
	(0.154)	(0.158)	(0.191)	(0.166)	(0.254)
ln(avg. energy cost) t - 1	-0.317*	-0.079	-0.168	-0.167	-0.1
	(0.184)	(0.188)	(0.222)	(0.189)	(0.254)
ln(avg. energy cost) t - 2	-0.223	-0.308**	-0.345*	-0.247	0.623***
	(0.152)	(0.151)	(0.183)	(0.165)	(0.232)
Firm age in years t	0.005	-0.004	0.003	0.008	-0.007
	(0.007)	(0.008)	(0.008)	(0.008)	(0.011)
Firm age in years t - 1	0.000	0.007	-0.002	-0.008	-0.008
	(0.007)	(0.007)	(0.008)	(0.007)	(0.008)
Firm age in years t - 2	-0.005	-0.006	-0.005	-0.006	-0.012*
	(0.007)	(0.007)	(0.009)	(0.008)	(0.007)
ETS t	-0.07	-0.08	-0.102*	-0.049	0.07
	(0.051)	(0.056)	(0.054)	(0.051)	(0.044)
ETS t - 1	0.049	0.053	0.065	0.099**	-0.135***
	(0.044)	(0.047)	(0.050)	(0.046)	(0.036)
ETS t - 2	-0.05	-0.033	-0.077	-0.093	-0.093*
	(0.060)	(0.056)	(0.072)	(0.060)	(0.050)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	33,980	33,980	33,980	33,980	30,834
Number of firms	6,206	6,206	6,206	6,206	5,602
KP LM statistic	73	73	73	73	68
Long run effect	-0.537***	-0.313*	-0.382*	-0.580***	0.759***
	(0.167)	(0.164)	(0.220)	(0.183)	(0.257)

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 are available in Table C.10. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption. The long run effect equals the sum of the coefficients of the logged average energy cost.

Table C.10. First stage regressions for the dynamic effects

	Ln(average cost) t	Ln(average cost) t - 1	Ln(average cost) t - 2
FEPI t	0.449***	0.151***	0.161***
	(0.030)	(0.032)	(0.036)
FEPI t - 1	0.049	0.448***	0.148***
	(0.031)	(0.036)	(0.035)
FEPI t - 2	0.021	0.033	0.546***
	(0.029)	(0.030)	(0.036)
Firm age in years t	-0.005*	0.000	-0.001
	(0.002)	(0.003)	(0.004)
Firm age in years t - 1	0.001	0.000	0.000
	(0.003)	(0.003)	(0.004)
Firm age in years t - 2	0.0000	-0.001	-0.004
	(0.003)	(0.002)	(0.004)
ETS t	0.024	-0.009	-0.022
	(0.019)	(0.015)	(0.015)
ETS t - 1	0.018	0.037*	0.012
	(0.019)	(0.019)	(0.014)
ETS t - 2	0.007	0.049**	0.085***
	(0.015)	(0.021)	(0.018)
Firm FE	X	X	X
Industry x Year dummies	X	X	X
Observations	36,424	26,720	25,855
Number of firms	6,841	5,316	5,153
F-statistic	29	30	45

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Firms' initial size and energy intensity both matter

Table C.11. Heterogeneous effects on environmental performance and economic performance

	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-1.146***	-0.732***	-1.084***	-1.406***	-0.782***	-0.573***	-0.914***
	(0.113)	(0.111)	(0.166)	(0.140)	(0.073)	(0.083)	(0.243)
ln(avg. energy cost) x SME (0/1)	0.311***	0.372***	0.278***	0.265***	0.381***	0.222***	0.421***
	(0.048)	(0.050)	(0.064)	(0.053)	(0.037)	(0.043)	(0.093)
ln(avg. energy cost) x energy use / worker	-0.159***	-0.154***	-0.117***	-0.143***	-0.135***	-0.165***	-0.117**
	(0.024)	(0.024)	(0.032)	(0.030)	(0.016)	(0.018)	(0.047)
Firm age in years	-0.027***	-0.035***	-0.012	-0.021***	-0.030***	-0.030***	0.006
	(0.007)	(0.007)	(0.009)	(0.007)	(0.004)	(0.004)	(0.013)
ETS (0/1)	0.117***	0.064*	0.156**	0.150***	0.157***	0.165***	0.127*
	(0.038)	(0.037)	(0.061)	(0.044)	(0.027)	(0.031)	(0.075)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	45,903	45,893	40,788	45,903	45,903	45,903	36,327
Number of firms	8,002	7,999	7,048	8,002	8,002	8,002	7,168
KP LM statistic	345	344	298	345	345	345	262

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 SME dummy equals 1 when the pre-sample number of workers of the firms is lower than 250. Energy use per worker is logged and corresponds to a pre-sample value to avoid endogeneity issues. The instrumental variables for the average energy cost and the interactions terms are the Fixed weight Energy Price Index (FEPI), the FEPI interacted with the SME dummy, and the FEPI interacted with the energy use per worker ratio. The first-stage regressions are reported in Table B.1. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Table C.12. Heterogeneous effects on energy intensity and input substitution

	Real energy intensity	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost)	-0.573***	-0.364***	-0.604***	-0.470***	0.488***
	(0.110)	(0.107)	(0.148)	(0.126)	(0.159)
ln(avg. energy cost) x SME (0/1)	0.089*	-0.071*	0.076	0.029	0.093
	(0.047)	(0.042)	(0.063)	(0.055)	(0.059)
ln(avg. energy cost) x energy use / worker	0.005	-0.025	-0.062**	0.047*	-0.042
	(0.023)	(0.022)	(0.031)	(0.028)	(0.030)
Firm age in years	0.003	0.003	0.001	0.000	-0.015*
	(0.006)	(0.007)	(0.008)	(0.007)	(0.008)
ETS (0/1)	-0.048	-0.039	-0.055	-0.038	-0.097*
	(0.037)	(0.035)	(0.042)	(0.042)	(0.054)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	45,903	45,903	45,903	45,903	40,778
Number of firms	8,002	8,002	8,002	8,002	7,045
KP LM statistic	345	345	345	345	297

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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 SME dummy equals 1 when the pre-sample number of workers of the firms is lower than 250. Energy use per worker is logged and corresponds to a pre-sample value to avoid endogeneity issues. The instrumental variables for the average energy cost and the interactions terms are the Fixed weight Energy Price Index (FEPI), the FEPI interacted with the SME dummy, and the FEPI interacted with the energy use per worker ratio. The first-stage regressions are reported in Table B.1. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Weighted regressions

Table C.13. Weighted TSLS estimates for environmental and economic performance

	Environmental performance				Economic performance		
	Energy use	Electricity use	Fossil fuel use	CO_2 emissions	Workers	Real output	Investment
ln(avg. energy cost)	-0.503***	-0.099	-0.662***	-0.807***	-0.181***	-0.022	-0.624**
	(0.121)	(0.117)	(0.185)	(0.165)	(0.066)	(0.072)	(0.308)
Firm age in years	-0.030***	-0.036***	-0.019**	-0.026***	-0.034***	-0.033***	-0.001
	(0.007)	(0.008)	(0.008)	(0.008)	(0.004)	(0.004)	(0.014)
ETS (0/1)	0.014	-0.039	0.087	0.055	0.051**	0.073***	0.063
	(0.036)	(0.035)	(0.058)	(0.043)	(0.024)	(0.028)	(0.079)
Firm FE	X	X	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X	X	X
Observations	45,893	45,883	40,778	45,893	45,893	45,893	36,317
Number of firms	8,000	7,997	7,046	8,000	8,000	8,000	7,166

Note: Robust standard errors clustered at the firm level in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. All outcome variables 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. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.

Table C.14. Weighted TSLS estimates for energy intensity and input substitution

	Real energy intensity	Energy use per worker	Energy use per material	Energy use per capital	Electricity / fossil fuel
ln(avg. energy cost)	-0.481***	-0.322**	-0.503***	-0.459***	0.649***
	(0.126)	(0.125)	(0.159)	(0.140)	(0.205)
Firm age in years	0.003	0.004	0.000	0.002	-0.008
	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
ETS (0/1)	-0.059	-0.037	-0.072*	-0.034	-0.128**
	(0.038)	(0.035)	(0.041)	(0.043)	(0.052)
Firm FE	X	X	X	X	X
Industry x Year dummies	X	X	X	X	X
Observations	45,893	45,893	45,893	45,893	40,768
Number of firms	8,000	8,000	8,000	8,000	7,043

Note: Robust standard errors clustered at the firm level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All outcome variables 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. Regressors are lagged one period. Energy use is the sum of electricity, natural gas, heating oil, and butane propane consumption. CO_2 emissions are emissions from energy consumption.