The Impact of Energy Prices on Socioeconomic and Environmental Performance: Evidence from French Manufacturing Establishments, 1997-2015

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ABSTRACT *

This paper evaluates the influence of energy prices on socioeconomic and environmental performance of French manufacturing establishments over the period of 1997-2015. To iden-tify price effects, we construct a shift-share instrument that isolates the exogenous variation in establishment-specific energy prices. Our results highlight trade-offs between environmental and socioeconomic goals: increases in energy prices reduce substantially energy consumption and CO2 emissions, and modestly employment and productivity. These trade-offs become starker when we simulate the impact of the planned French carbon tax. Energy price impacts are larger in the long- rather than in the short-term, in trade-exposed and in energy-intensive sectors, and slightly skill-biased towards technical workers. Finally, such impacts appear up-per bounds when we account for the impact of energy prices on inputs’ reallocation across establishments, but lower bounds when we account for the positive influence of energy prices on the exit probability.

KEY WORDS

Energy prices, environmental and economic performance, establishment-level analysis, employment, skills, Porter Hypothesis.

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1 Introduction

The impact of environmental policies on business performance has been a long-standing and controversial topic in the political debate, especially so because urgent responses to climate change have to be compatible with tightening government budgets and increasing competitive pressure from emerging countries. While stringent environmental policies produce valuable benefits for society as a whole, their impact on industrial production, employment and productivity is often cited as the main reason to provide generous policy exemptions to the most polluting sectors (Ekins and Speck, 1999; Martin et al., 2014). Informing the policy debate on the possible trade-offs between economic and environmental goals is thus much needed, but evidence is scant due to data limitations or not relevant for a high-carbon price scenario because of the low stringency of existing climate policies (i.e. EU-Emission Trading Scheme, EU-ETS).

This paper contributes to this debate by proving a comprehensive evaluation of the responses of French manufacturing establishments to large increases in energy prices, our proxy of environmental policy stringency. The combination of three rich statistical sources gives us the unique opportunity to study the joint socioeconomic and environmental impacts of energy prices over a long time span (1997-2015).[1] To identify the impact of energy prices, we construct a shift-share instrument combining initial establishment-specific shares of different energy inputs (i.e., gas, electricity, coal, oil) with nation-wide energy price shifts.

The use of energy prices is attractive because most policies directed at reducing air pollution or contributing to climate change mitigation result in an increase (directly or indirectly) in the cost of burning fossil fuels (Aldy and Pizer, 2015). Importantly, energy prices exhibit a historical increase of approximately 50% in our data, making our policy evaluation to closely resemble what would happen in ambitious carbon pricing scenario, such as those enacted by the French government with the Energy Transition Law of 2015 and planned by all countries that

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[1] We combine three datasets provided by the French Statistical Office (INSEE): the survey EACEI (Enquête sur les consommations d'énergie dans l'industrie) on energy purchase and consumption (by energy input) of French manufacturing establishments, DADS Postes (Déclaration Annuelle des Données Sociales) on employment and wages for different occupations of French establishments and FARE-FICUS on firms' balance sheets.

ratified the Paris Agreement on climate change mitigation.

The features of our data allow to contrast the impact of energy prices at both the establishment- and the firm-level and for multi- and single-establishment firms, and to identify the sectors and workers that are likely to be mostly affected by climate policies. At the establishment-level, we can directly measure wage and employment impacts; the latter has been the focus of a controversial debate on jobs vs. the environment (Greenstone, 2002; Morgenstern et al., 2002; Walker, 2011), often used to undermine the political acceptability of climate policies (Vona, 2019). Determining the sign and magnitude of the cross-elasticity between energy prices and labour demand remains an unresolved empirical question as two mechanisms offset each other (Berman and Bui, 2001; Morgenstern et al., 2002). On the one hand, higher energy prices negatively affect overall production and thus labour demand. On the other hand, more expensive energy will be substituted with other inputs, such as labour and capital. Similarly, wage effects conflate compositional changes in the workforce and a pass-through of higher costs to wages. By differentiating the effect by skills groups, our paper makes a first step in the direction of assessing the role of compositional changes, while previous firm- and establishment-level analyses only studied the impact on total employment.

At the firm-level, we are able to estimate also labour productivity and Total Factor Productivity (TFP) impacts. In doing so, we extend our contribution to yet another controversial topic, such as the competitiveness impact of environmental policies (see, e.g., Dechezleprêtre and Sato, 2017). The traditional view is that environmental regulation distorts the optimal allocation of inputs, thus lowering efficiency (Palmer et al., 1995; Jaffe and Palmer, 1997; Greenstone et al., 2012). However, by changing the relative prices of polluting inputs with respect to other inputs, higher energy prices will also induce innovation directed at substituting or improving the efficiency of most polluting inputs (Acemoglu et al., 2012). The alternative view, known as the Porter Hypothesis (Porter and van der Linde, 1995), is that well-designed environmental regulation can lead to benefits exceeding compliance costs and thus to a positive impact on firm competitiveness (Ambec et al., 2013). Indeed, in the presence of bounded rational firms and asymmetric information, new regulations reveal opportunities for innovation, organizational improvements and changes in the input mix that were not yet considered by managers.

Our results highlight trade-offs between environmental (energy consumption and emissions) and economic goals (employment and competitiveness) due to increasing energy prices. Using our favourite instrumental variable specification, the own-elasticity of energy consumption (-0.5) and CO2 emissions (-1.1) indicate that policies increasing energy prices are very effective in reducing the environmental impacts of economic activities. On the other hand, higher energy prices reduce employment and total factor productivity, although the estimated cross-elasticities are substantially smaller than those of environmental goals, i.e., -0.08 for employment. Importantly, short-term effects are significantly smaller than the long(er)-term (3-years) ones for CO2 emissions, energy demand and employment. Effects also differ across sectors and occupations. The job vs. the environment trade-off is particularly striking in energy-intensive sectors and trade-exposed sectors and it is further amplified when we simulate the effect of the planned French carbon tax. Changes in labour demand are not homogeneous across skill groups, but the skill biasness in favour of technicians and against manual workers is rather small. Finally, we show that employment effects are mitigated by labour reallocation across establishments within the same firm, while the positive effect of energy prices on the probability of exit might suggest that our estimates represent a lower-bound of the true effect.

Besides reassessing old debates on jobs vs. the environment and competitiveness impacts within a unified database, we contribute to the growing firm-level literature on the evaluation of environmental policies in three ways. First and foremost, compared to the few joint evaluations of environmental and socioeconomic outcomes, we cover a longer time period and exploit a new source of policy variation, associated with substantial increase in energy prices. Martin et al. (2014) evaluate the impact of the UK Climate Change Levy on energy consumption and employment over the period 1999-2004. Differently from us, they find no trade-off between jobs and the environment, but this may be due to the relatively mild increase in policy stringency for the treated group or by the short time span of their analysis. The voluminous literature evaluating the effect of the EU-ETS at the firm-level reach the conclusion that large impacts on emission reduction do not come at the cost of losing competitiveness and jobs. Again, the lack of stringency of the EU-ETS is a serious candidate to explain the absence of trade-offs.[2]

Second, our data allow to analyse within-firm across-establishment reallocation effects and exit, thus contributing to understanding the extent to which compositional shifts amplify or mitigate energy price impacts. This analysis is important to link the instrumental variable estimates, which are necessarily local, to the aggregated and general equilibrium effects of energy price changes. Previous research estimates aggregated effects using either structural models (Morgenstern et al., 2002) or decomposition analyses (Hille and Möbius, 2019). We complement these studies by estimating input reallocation within multi-establishments firms as well as the impact of energy price on the exit probability.

Finally, our paper contributes to the growing literature on the evaluation of energy price effects on performance in three ways (Deschênes, 2011; Kahn and Mansur, 2013; Aldy and Pizer, 2015; Hille and Möbius, 2019). First, we move to finer level of disaggregation (establishment and firm) which allows investigating heterogeneous impacts along multiple dimensions. Second, we can differentiate short- and long-term impacts, thus uncovering the persistence of energy price shocks on the affected firms. Third, we consider multiple energy inputs while previous studies mostly focused on electricity. Not only this feature of our data makes this study more general than previous ones, but it is also useful to resolve endogeneity issues in the estimation of price effects and to simulate policy impacts to energy inputs with different carbon contents.

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[2] Several papers provide evidence on the impact of the EU-ETS on employment. Wagner et al. (2014) estimate that French manufacturing establishments in the EU-ETS decreased employment by approximately 7% compared to similar non-ETS establishments, while Abrell et al. (2011), considering 24 countries during the first phase of the EU-ETS, found a smaller (-1%) effect. Other studies finding no effect on employment are: Anger and Oberndorfer (2008) for Germany, Marin et al. (2018) for 19 EU countries and Dechezleprêtre et al. (2018) for all countries in the EU-ETS. When considering emissions, Wagner et al. (2014) estimate a reduction of 15-20% for France, Petrick and Wagner (2014) estimate a reduction of about one fifth for Germany and Dechezleprêtre et al. (2018) estimate a reduction of 10-14% for France, Netherlands, Norway and the UK.

The paper is organized as follows. Section 2 first describes a series of stylized facts about energy consumption and the costs of French manufacturing establishments. We describe the evolution of energy price heterogeneity across establishments in Section 2. Section 3 illustrates the empirical strategy for estimating the effect of energy prices, while Section 4 discusses the main results and several extensions and robustness checks. Section 5 concludes.

2 The changing structure of energy prices in French manufacturing

This section documents the evolution of energy prices and quantities of French manufacturing establishments over two decades. As an essential step toward the evaluation of the impact of energy prices on establishments' performance, we analyse cross-establishment heterogeneity in both energy prices and the use of different energy inputs.

2.1 Data sources

The main source of information about the energy use and expenditures of French manufacturing establishments over the period of 1997-2015 is the EACEI survey (Enquête sur les consommations d'énergie dans l'industrie). EACEI collects detailed information on energy consumption and expenditure by energy input (12 inputs) for a representative sample of manufacturing establishments with at least 20 employees. The sample design is standard for this kind of survey: all establishments with more than 250 employees are requested to participate in the survey, while establishments with between 20 and 250 employees are sampled according to a stratified (by nomenclature of activities - NTE - dedicated to energy consumption, workforce bands, and region) design (see Wagner et al., 2014, and Appendix A for further details).[3]

Concerning economic variables, our primary measures are the average wage per employee

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[3] In a previous version of this paper, we reported different descriptive statistics and results. There was indeed an error in our treatment of the raw EACEI data, which are already multiplied by the sampling weights until 2004 by the INSEE (the French statistical office) to construct aggregate statistics. In this version of the paper, we divide the raw data by the sampling weights before 2004.

and the total employment in full-time equivalents and by occupation groups in DADS Postes (Déclaration Annuelle des Données Sociales) for the universe of French establishments. We link this information from DADS Postes to EACEI establishments by means of a unique identifier of the establishment (SIRET). Because establishments are not required to compile and submit their balance sheet and income statement, we cannot estimate the effect of energy prices on productivity at the establishment level. In an extension, we use the balance sheet and income statement information from the FICUS/FARE databases to estimate the impact of energy prices on different measures of productivity at the firm level. Using a unique firm identifier (SIREN), we keep the firms for which all establishments were surveyed in EACEI. Note that both DADS and FARE-FICUS are available for the entire universe of French establishments and firms, respectively. As a result, the matching with EACEI is perfect.

2.2 Measure of energy prices

Similar to the work of Davis et al. (2013) on electricity prices, what we label as energy price is the average unit cost of energy, which is the ratio between total energy expenditure and total energy consumption. This measure does not say anything about marginal energy prices or the detailed structure of tariffs faced by an establishment. This limitation, however, is largely compensated by the advantage of having access to establishment-specific information for energy prices, energy mixes and key economic variables over a long time span. To the best of our knowledge, this represents a unique advantage of our data compared to those used in related research.

In the following, we will use the word 'price' to refer to the unit cost of energy, that is:

$$p_{it}^{E} = \sum_{j=1}^{12} \phi_{it}^{j} p_{it}^{j}, \tag{1}$$

where ϕ_{jit}^{j} is the share of energy consumption of input $j = 1...12$ (i.e., natural gas, electricity, etc.) in total energy consumption, while p_{it}^{j} is the average unit value cost of energy input j paid by establishment i at time t. Energy consumption for all energy inputs is converted into kWh (kilowatt hour) equivalent values. By using a comprehensive measure of energy prices rather than electricity prices only, we can build establishment-specific exposure to shocks to particular energy inputs, which is convenient to study price shocks to inputs with different carbon content.

2.3 Basic facts

As is transparent from equation 1, cross-establishment heterogeneity in energy prices depends on differences in both the energy mix and establishment- and input-specific energy prices. Figure 1 reports the average energy mix of French manufacturing establishments, weighted by sampling weights multiplied by establishments' energy consumption. These values appear relatively stable throughout the period of 1997-2015. The French manufacturing sector heavily relies on energy inputs with low carbon content: the consumption of gas and electricity (mostly generated from nuclear power plants) jointly accounts for approximately 65.6% (average 1997-2015) of total energy consumption. The energy mix became cleaner over time as long as steam increased at the detriment of oil and coal, which, combined, declined from 34.6% to 25.5% of total energy consumption.

[Figures 1 and 2 about here]

Changes in establishment-specific prices for different energy inputs represent the other main source of variation in the average energy price. Figure 2 summarizes the trends of the average unit cost of energy (euro per kWh deflated to 1997 values using the GDP deflator) for different energy inputs. Three facts are worth to be discussed.

First, with the exception of electricity, average prices of all inputs increased substantially over the period 1997-2011 and declined afterwards. Unsurprisingly, gas and oil prices appeared more responsive to global demand factors than electricity, experiencing an upward trend between the entry of China to the WTO (2001) and the Great Recession and a slowdown thereafter. By contrast, electricity kept increasing until 2015 since it is mostly correlated with domestic policies, such as the introduction of a tax to support renewable energy generation (‘Contribution au Service Public de l’Electricité’).[4]

Second, while electricity remained by far the most expensive energy input, the ratio between the price of electricity and the average price of other inputs decreased in the two decades covered by our analysis. To illustrate, one kWh of electricity was approximately 4.3 times more expensive than a kWh of gas in 1997 and approximately 2.2 times more expensive in 2015.

[Table 1 about here]

Third, Table 1 suggests that yearly price changes are not highly correlated. Except for some co-movements in inputs that are either obvious substitutes (e.g. butane-propane vs heating oil) or that use the same raw material (e.g. different types of oil products), we observe relatively weak correlations, especially between electricity prices and the price of carbon-intensive fuels (always below 0.5). Such a weak correlation across input-specific price shocks lends support to the use of a shift-share instrument for energy prices. Indeed, exposure to price shocks exhibits enough across-establishment variation to identify energy price impacts.

[Table 2 about here]

Although the energy mix appears to be rather stable over time, and so exposure to input-specific shocks, what really matters for evaluating price impacts is the degree of cross-establishment heterogeneity in energy intensities and mixes. Energy intensity, e.g. the incidence of energy-related costs over value added, is a good proxy of the degree of cost-exposure to changes in energy prices, while the energy mix is a good proxy of exposure to shocks that are specific to a

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[4] In the 1990s and 2000s, the French energy sector was characterized by very important regulatory changes. As in other countries, these changes were aimed at improving the functioning of market mechanisms within the concentrated and vertically integrated French energy sector and at reducing the environmental impact of energy consumption in the industrial sector. For instance, the ‘Contribution au Service Public de l’Electricité’ has been introduced to finance renewable energy generation. The tax is levied on all final consumers (households and firms) of electricity and is aimed at refunding to EDF for the obligatory purchase of electricity from renewable energy and co-generation. The tax per MWh increased rapidly over time, growing from 3 euro in 2002 to 16.5 euro in 2014 and 19.5 euro in 2015, thus explaining at least part of the sustained increase in electricity prices documented in Figure 2. An analysis of the relation between energy prices and such regulatory changes is carried out in a previous version of this paper.

certain energy technology. Table 2 reports the averages and standard deviations (in parentheses) of energy intensities, prices and mixes broken down by sector (2-digit NACE rev. 2). The bottom line is that all these measures exhibit substantial variation both between and within sectors. Together with the weak correlation across price shocks, this finding is important for our estimation strategy: changes in the relative prices of different energy inputs have heterogeneous impacts on the average unit cost of energy of establishments with *different* energy mixes and *similar* energy intensities.

[Figure 3 about here]

An important insight from Table 2 is that average energy prices appear lower in sectors that, as Metals (NACE 24) and Chemicals (NACE 20), are more energy-intensive. To better understand the price-quantity relationship and whether it has changed over time, we estimate cross-sectional elasticities of energy prices (average, electricity and gas) to the quantity consumed conditional on sector (2-digit NACE) and region (NUTS2) dummy variables as in Davis et al. (2013). The absolute values of the estimated elasticities (all negative) are reported in Figure 3, which reveals a large decline in elasticity (and thus in quantity discounts) until 2011 (from 16.6% - 1997 - to 7.8% - 2011 - for total energy prices) followed by a reversal in the last four years of our analysis. Overall, this fact suggests that reductions in quantity discounts harmed large consumers of energy for which adjustment costs may be higher. Therefore, differently from existing environmental policies that offer generous exemptions to the most polluting sectors, the price variation examined in the present study may be more suitable to reveal what would happen in case of the adoption of a policy directly targeting high-polluters.

3 Empirical strategy

This section illustrates the empirical strategy used to estimate the impact of energy prices on establishment performance. We consider two dimensions of establishment performance. The first set of dependent variables refers to environmental performance: total energy consumption (in kWh) and CO2 emissions from energy use (in tons).[5] The second set of dependent variables are measures of socioeconomic performance. We primarily focus on 'core' labour market outcomes that are available at the establishment level; that is: employment levels in full-time equivalents (FTE), the average wage per FTE employee and the share of employment of specific occupational groups.

Our starting point is the following equation:

$$\log(y_{it}) = \alpha_i + \beta \log(p_{it}^E) + X_{it}'\gamma + \epsilon_{it}, \tag{2}$$

where y_{it} is the outcome variable (e.g. energy consumption, CO2 emissions, employment, average wages paid) of establishment i in year t, α_i is the establishment fixed effect, p_{it}^E is the average unit cost of energy (euro per kWh) of establishment i in year t, X_{it} is a vector of control variables, and ϵ_{it} is the error term.

In our favourite specification, the vector X_{it} includes sector (2-digit NACE rev.2) by year and region (NUTS2) by year dummy variables. Region- and sector-specific year dummies account for unobservable demand or supply shocks that affects all establishments in a region or sector and could be correlated with both energy prices and the outcome variables. To directly test the robustness of our estimates to the inclusion of covariates, we present also a less-demanding and a more-demanding specification. In the former, the vector X_{it} includes only region-by-year dummies. In the latter, the vector X_{it} also includes: i) year-specific EU-ETS dummy variables to account for the impact of the EU-ETS in a flexible manner,[6] ii) a dummy for the need of peaks in electricity consumption interacted with time dummies;[7] iii) year-specific dummies for

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[5] We compute CO2 emissions by multiplying each energy input by its technical CO2 emission factor (see Appendix A). Since electricity and steam do not generate any direct emissions, observations for which all energy consisted of electricity and/or steam were automatically excluded from the estimation sample for this variable.

[6] A comprehensive policy evaluation on the impact of the EU-ETS on the performance of French establishments is given in Wagner et al. (2014).

[7] The peak-exposure dummy is equal to one for establishments that in their first year in EACEI were in the fourth quartile of the ratio between subscribed capacity for electricity consumption - MW - and actual annual electricity consumption - MWh. Accounting for the exposure to peak-hour electricity prices is also important, as

establishment size in the first year of observation (10-49 employees, 50-99 employees, 100-249 employees, 250-499 employees and 500 or more employees) capturing different growth potential related to initial size (see, e.g., Bottazzi et al., 2011).

Importantly, what we estimate is primarily the within-establishment response to a change in energy prices. Whatever happens to entry, exit and the reallocation of inputs and production across establishments is not incorporated in $\hat{\beta}$, thus the aggregated effect of energy prices can differ from the one estimated in our reduced-form model. We tackle this issue in Section 4.5, where we asses the influence of energy prices on exit and energy and labour reallocation within the same firm.

3.1 Endogeneity issues

Endogeneity is a concern in our estimation framework due to the presence of omitted variables. There are three types of variables that are difficult to observe but likely to be correlated with both our outcome variables and energy prices. First, if establishments experience an idiosyncratic negative demand shock d_{it}, they reduce output and the demand for inputs, including energy and employment. In turn, a lower demand for energy increases the average unit cost of energy through a reduction of quantity discounts.

Second, endogenous energy-saving technical change a_{it}^{E}, which is empirically well documented (Popp, 2002; Hassler et al., 2015), simultaneously reduces the consumption of energy and quantity discounts offered to firms, thus increasing the average unit cost of energy. This implies that a_{it}^{E} biases the impact of energy prices on energy-related outcomes in the same direction as d_{it}. By contrast, the correlation between a_{it}^{E} and employment should be zero. Finally, as a response to an increase in energy prices, technical change can facilitate the substitution of energy with labour and capital (Hassler et al., 2015). A change in the elasticity of substitution ε_{it} between labour and energy will be positively (resp. negatively) correlated with labour (resp. energy)

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this variable incorporates useful information about the type of technology used by the firm, which is correlated with both energy prices and performance.

demand.

To guide our expectations regarding the sign for the omitted variable bias for labour L (our example for socioeconomic outcomes) and energy E (our example for environmental outcomes), it is useful to inspect the formula of the omitted variable bias (Angrist and Pischke, 2009):

$$\hat{\beta}_y = \frac{Cov(y_{it}, p_{it}^E)}{Var(p_{it}^E)} = \beta_y + \underbrace{\gamma_{y,d}\delta_{p,d}}_{\text{-}} + \underbrace{\gamma_{y,a^E}\delta_{p,a^E}}_{\text{-}} + \underbrace{\gamma_{y,\varepsilon}\delta_{p,\varepsilon}}_{\text{+ L, - E}}, \tag{3}$$

where δ_s are the coefficients of the regression of energy prices on the vector of omitted variables $[d \; a^E \; \varepsilon]$, while $\hat{\gamma}$s are the coefficients of the regression of the outcome variables on p, the standard controls and the vector $[d \; a^E \; \varepsilon]$. Note first that all shocks are positively correlated with energy prices (that is, δ_s are all positive) and thus the sign of the biases depends only on the correlations between the outcome and the omitted variables. The negative demand shock reduces the size of the estimated coefficient $\hat{\beta}_y$ with respect to the true one, β_y. Indeed, $\gamma_{y,d}$ is negative for both E and L. Energy-saving technical change has no effect on L but a negative one on E. The change in the possibility of substituting energy for labour is positively correlated with L and negatively correlated with E.

As a result, we should observe a downward bias in the OLS estimates of β_y (a negative parameter); that is: OLS overestimates the magnitude of the own-elasticity of energy demand to price. On the other hand, the direction of the bias is unclear for labour and depends on the relative magnitudes of the downward bias associated with unobservable demand shocks and of the upward bias related to the substitution of labour for energy.

3.2 Shift-share instrument

One way to deal with these multiple omitted variable biases is to identify an instrumental variable (IV) that is correlated with exogenous variation in energy prices but uncorrelated with establishment-specific demand shocks and endogenous technological responses to changes in energy prices. To fulfill this requirement, we propose a shift-share instrument (Bartik, 1991) that combines the nationwide prices of different energy inputs with the time-invariant establishment-specific energy mix and has been used elsewhere to address the issue of energy price endogeneity (see, e.g., Linn, 2008; Sato et al., 2019; Marin and Vona, 2019). Specifically, we weigh the average national price of each energy input j (p_t^j) for the pre-sample energy share of the corresponding energy input used by the establishment ($\phi_{i,t=t_0}^j$):

$$p_{it}^{IV} = \sum_{j=1}^{12} \phi_{i,t=t_0}^j p_t^j. \tag{4}$$

For each establishment, nationwide price variations are constructed net of establishment prices and thus are uncorrelated with establishment-specific shocks. Blocking the energy mix before the entry of the establishment in the estimation sample shuts down the influence of endogenous technical change that mostly operates through changes in the energy mix. To mitigate the concern that forward-looking managers forecast the evolution of input-specific energy prices in the coming years and choose the energy mix in the year t accordingly, the pre-sample measure of the establishment energy mix is lagged by at least 3 years with respect to the first observation in which the establishment joins the estimation sample. Consequently, the estimation sample runs from 2000 to 2015 rather than from 1997 to 2015. This also implies that in addition to the two observations in the EACEI survey per establishment that are used to estimate a fixed effect model, we need to observe the establishment one more time to build our instrument.[8]

While the establishment fixed effect accounts for time-invariant unobservable differences across establishments, in Appendix C we explicitly test for the presence of pre-trends (Goldsmith-Pinkham et al., 2018). Indeed, establishments with different initial energy mixes may exhibit different pre-trends in the outcome variable before 2000 (the first year used for estimating the price impacts). As illustrated in Table C1, only when we account for both region-year and sector-

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[8] In Appendix B, we illustrate that there are systematic differences between the establishments in the estimation sample and the EACEI establishments that were excluded from the estimate. In particular, the former are larger and more energy intensive than the latter, which is not surprising given the sample design of the EACEI dataset; see Appendix A. It should be noted, however, that the estimation sample represents on average as much as 70.7% of the reference universe of establishments, accounting for 81.2% of the energy consumption and for 77.8% of the total employment.

year dummies we observe no significant difference in pre-trends depending on the initial energy mixes. This result has two implications for our analysis. First, the reliance of our instrument on a time-invariant energy mix does not bear the risk of capturing pre-existing trends that are correlated with the energy mix itself. Second, controlling for sector-year dummies matters for the validity of our IV strategy.

A final concern regarding the validity of our IV strategy refers to the fact that the current adjustment in the input mix responds to both past and present price shocks, thus the estimated coefficients conflate short- and long-term effects. To explicitly account for the adjustment dynamics, we follow Jaeger et al. (2018) by estimating a specification of equation 2 in which we include up to two additional lags of the price variable and instrument each lagged variable with the corresponding instruments, built as in equation 4. As we rely on an unbalanced panel of establishments, due to the design of the EACEI survey and to entry/exit, the sample size for specifications with lagged prices is substantially smaller and over-represents large establishments. For this reason, our benchmark specification is the one with no lags in energy prices, while this extension is used to interpret price effects as short- or long-term effects.

4 Estimation results

This section is organized in five distinct subsections. The first presents the main results at the establishment-level. The second focuses on the heterogeneous responses of different skill groups and sectors. The third quantifies the magnitude of the estimated effects with respect to the historical increase in energy prices and the planned French carbon tax. The fourth presents firm-level results to gauge the impact of energy prices on productivity, while the fifth examines the reallocation of inputs (energy and employment) across establishments within the same firm as well as the impact on exit.

4.1 Jobs vs the environment trade-off

The baseline results are reported in Table 3, where we present both the fixed effect model (FE) and the fixed effect model with energy prices instrumented as described above (IV-FE).[9] We compare specifications with different sets of control variables, as described in section 3. Recall that, due to the unavailability of sales data at the establishment-level, the first and main set of results is on the possible job vs. the environment trade-off. Note also that the log-log specification of equation 2 leads to a direct interpretation of the estimated coefficients as own-elasticities (for energy demand and, with slight abuse of language, CO2 emissions) or cross-elasticities (for labour demand and wages).

Across the board, the impacts of energy prices conform to our expectations. First, the estimation biases are consistent with predictions of equation 3. For energy and CO2 emissions, the FE model substantially over-estimate the magnitude of price elasticities. The bias is large, especially for energy demand, since all omitted variables make the price-quantity relation steeper. Conversely, we observe a negligible bias for employment impacts, consistent with the fact that omitted variables cancel each other out. Reassuringly, the point estimates are very similar regardless of the set of controls used, suggesting that the influence of pre-trends is minimal even in less-demanding specifications that exhibit a certain degree of non-parallel pre-trends in employment depending on the initial energy mix. Overall, our results reveal the importance to properly account for endogeneity of energy prices in order to retrieve reliable impacts on environmental outcomes; thus, in the remainder of the paper, we will focus on the IV results.

Second, while an increase in the unitary energy cost decreases the use of environmental and labour inputs, the own-elasticities of environmental outcomes are approximately an order of magnitude larger than the cross-elasticities of labour demand. Concerning the environmental impacts, the IV estimate of the own-price elasticity of energy consumption is -0.5 in our favourite specification (fourth column). This number is larger than that estimated in sector-level studies

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[9] First-stage results are reported in Table E1 in Appendix E, while the F test for the strength of the excluded instrument is reported in Table 3 and is always well above the usual cut-off of 10.

(Adeyemi and Hunt, 2007; Agnolucci, 2009), but in line with the price elasticity of energy consumption for Danish firms found by Bjorner and Jensen (2002).[10] Interestingly, CO2 emissions are more responsive to energy price shocks than energy consumption with an elasticity of -1.13 in our favourite specification (fourth column). This result underscores the higher innovative effort of CO2-intensive establishments compared to electricity-intensive ones. Expectations of future carbon price increases may represent a possible explanation of the different behaviour of carbon-intensive establishments. However, adding ETS-specific year dummies, a proxy of the establishments most likely to be affected by future increases in carbon prices, does not alter the magnitude of the CO2 elasticity (sixth column).

Concerning the labour market impacts, changes in energy prices have virtually no effect on wages. By contrast, effects on FTE employment are statistically significant in our favourite specification (fourth column) and in the more demanding model (sixth column), but only weakly significant in the less demanding specification without sector-by-years dummies (second column). In terms of magnitude, the effects are in line with (but slightly smaller of) those found by previous studies of Kahn and Mansur (2013) and Deschênes (2011) (i.e., between -0.10 and -0.15 there against our favourite cross-elasticity of -0.08). While the magnitude of these effects do not lend support to the job killing argument, next two sections identify the sub-groups for which the effect become economically meaningful.

[Table 3 about here]

The next step is to explore whether effects are persistent and thus capture the long-term establishment response to energy price shocks. We follow the approach proposed by Jaeger et al. (2018) by augmenting the specification in equation 2 with two lags in energy prices.[11] We stop at two lags of energy prices not to exacerbate the selection bias in our estimation sample, whose

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[10] The implicit price elasticity of energy consumption for the UK found by Martin et al. (2014) is even larger, i.e. -1.44.

[11] These additional variables are instrumented in a straightforward manner taking lags of equation 4. First-stage results for this augmented specification are reported in Table E2 in Appendix E. Each instrument is a good predictor of the endogenous variable in the same period, which means that there is sufficient variation in the establishment exposure to different 'shifts' (i.e., national input-specific energy prices).

size drops by more than 40% when adding two lags. As discussed above, the goal of this analysis is to illustrate the difference between short- and long-term effects; therefore, Table 4 reports both the short- and the long-term effect for the same reduced estimation sample. The main message of this extension is that short-term elasticities are significantly smaller than long-term ones, computed as the cumulative effects of current and past energy prices. The difference ranges between 50% for CO2 emissions (-1.32 vs. -0.86) to approximately 2 times for employment (-0.13 vs -0.06) and energy demand (-0.5 vs. -0.25). Since the extensions presented in next sections entail reductions in sample sizes or splitting, we keep using the specification without lagged terms in energy prices to preserve an adequate sample size and representativeness.

[Table 4 about here]

In Appendix D we perfom two additional robustness checks. First, we condition equation 2 on the level of firms' sales (Table D1).[12] The objective is to test whether the negative effects, especially so the one for employment, are driven by a scale effect on output as in the related paper by Cox et al. (2014). Although unsurprisingly sales are positively correlated with input use, the estimated elasticities remain in line with the baseline results, with a small increase in the employment effect.

Second, we aggregate up establishment-level information at the firm-level, where key decisions are taken, and estimate our favourite specification for the four different outcome variables (Table D2).[13] Overall, baseline results are confirmed in sign and statistical significance, even though the magnitude of the estimated elasticities is larger than in our favourite establishment-level estimates for energy consumption and CO2 emissions.

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[12] Firm's sales are retrieved from the FICUS/FARE database. Obviously, firm-level sales are an imperfect proxy of demand shock at the establishment-level.

[13] The firm-level analysis is only possible for either single-establishments firms or for firms for which all establishments were surveyed in EACEI in a specific year. This clearly generates a sample selection bias that does not allow a straightforward comparison with our establishment-level estimates. For comparison, Table D2 also the estimates at the establishment level.

4.2 Heterogeneous effects

The aggregate results may hide a substantial degree of heterogeneity across sectors, establishments and occupations. We explore these dimensions of heterogeneity one by one in this section.

Concerning skills, which represents a novel contribution of this paper, energy prices may induce technical and organizational changes within the establishment that can be skill biased. At a more aggregate level of analysis, Vona et al. (2018) (for US regions) and Marin and Vona (2019) (for industrial sectors in EU countries) show that the bias is in favor of technical skills and against manual workers. Following these works, our new dependent variables in equation 2 are the employment shares of four occupational categories (see Table A1 in Appendix A): managers and professionals, technicians, high-skilled manual workers ("trained" blue collar workers) and low-skilled manual workers ("untrained" blue collar workers). We exclude clerical jobs, as they are less affected by organizational changes induced by environmental policies.

[Table 5 about here]

Table 5 contains the main results of this extension. Also at the establishment-level, we find that an increase in the price of energy induces an increase in the relative demand for technicians and a decrease in the relative demand for low-skilled manual workers, even though the latter effect is imprecisely estimated (p-value=0.16). Different from previous studies, no effect is found on professionals, which can be explained by the fact that this broad category include professions (e.g., lawyers) that are unlikely to be directly involved in the tasks required to provide new energy saving solutions.

As suggested by the descriptive evidence in Table 2, the incidence of higher energy prices is expected to vary substantially depending on the energy intensity of the sector. In line with previous studies (Kahn and Mansur, 2013; Aldy and Pizer, 2015), we expect that more energy-intensive sectors are more sensitive to changes in energy prices than less energy-intensive sectors. To explore this possibility, we add an interaction term between energy price and initial sectoral energy intensity (3-digit NACE) to equation 2.[14] Results in Table 6 confirms that the impact of energy price is increasing in sectoral energy intensity for all the four outcome variables considered at the establishment-level, even though the difference in the net effect between the first and tenth decile is generally small in magnitude. An important result is that the cross-elasticity between energy prices and wages become negative and statistically significant for sectors in the top decile of energy intensity .

[Table 6 about here]

Sectors that are more exposed to international competition are likely to be more sensitive to changes in energy prices. Above all, higher prices of intermediate inputs like energy decrease an establishment's international competitiveness because prices for its final goods and products are determined in international markets, and thus, there is limited scope to adjust mark-ups (Morgenstern et al., 2002). Furthermore, openness to trade is positively correlated with the risk of relocating production to countries with laxer environmental regulations (Ederington et al., 2005). We re-estimate equation 2 including an interaction term between energy prices and a dummy variable that equals one for trade-exposed (3-digit NACE) sectors, defined on the basis of the trade-related criterion for exemption from auctioning of EU-ETS allowances introduced by the European Commission (see Table A2 in Appendix A). Table 7 shows that employment effects are concentrated in trade-exposed sectors. Effects on CO2 emissions and energy demand are also stronger in trade-exposed sectors, possibly because these sectors are capable to relocate dirty tasks in countries with less stringent environmental regulations (Cherniwchan et al., 2017).

[Table 7 about here]

A final concern relates to the heterogeneous response of single-establishment firms compared to multi-establishment firms. The effect is expected to be larger for establishments hit by

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[14] Initial sectoral energy intensity is measured as the average ratio of energy expenditure over value added in the pre-sample period 1997-1999. Clearly, establishment or firm energy intensive would be endogenous.

energy price shocks in multi-establishment firms because managers can easily relocate production within the same firm. To capture different effects between multi- and single-establishment firms, we interact energy prices with a time-varying dummy variable for establishments in multi-establishment firms. Table 8 shows that indeed multi-establishment firms are more responsive to changing energy prices, reorganizing production in such a way to achieve slightly larger reductions in energy consumption and CO2 emissions. Employment is also more sensitive to energy prices in establishments that belong to multi-establishment firms, while wages go in the opposite direction in multi-establishment firms suggesting the presence of different bargaining mechanisms in larger firms (Carluccio et al., 2015). However, this extension is unable to isolate the effect of across-establishment reallocation of inputs from an effect related to size. Section 4.5 delves into this issue by isolating the across-establishment reallocation effects.

[Table 8 about here]

4.3 Quantifying energy price impacts

In this section, we provide two different quantifications of the effects discussed above. First, we contrast the effect of the historical changes in energy prices (2000-2015) on our outcome variables with the actual historical changes of these variables. In doing so, we differentiate the predicted changes in energy prices for different subsamples of establishments and consider subsample-specific estimated effects (as estimated in Section 4.2).

Second, as in Aldy and Pizer (2015), we compute the counterfactual impact of expected changes in energy prices due to the planned (in the time span of our data) introduction of a French carbon tax of 56 euro per ton of CO2 in 2020.[15] To provide a counterfactual quantification of the environmental and economic impacts of such carbon tax, we first compute the establishment-specific impacts of the tax on energy prices using the establishments' energy mix

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[15] On 17 August 2015, the French parliament approved the so-called 'Energy Transition Law' (loi no. 2015-992), which sets ambitious objectives for climate change mitigation going beyond the EU ones (i.e., the 2030 Climate and Energy Framework), such as a 40% reduction in greenhouse gas emissions by 2030 (from 1990 levels). As a main tool to achieve these ambitious goals, the law imposes the gradual introduction of a carbon tax: 22 euro per ton of CO2 by 2016, 56 euro per ton of CO2 by 2020 and 100 euro per ton of CO2 by 2030.

for the year 2015. As a second step, we straightforwardly compute the impact of the policy-induced change in energy prices on our outcome variables using the IV elasticities estimated above.

[Table 9 about here]

Results are shown in Table 9, with historical energy price changes shown in Panel A and the quantified impact of the carbon tax in Panel B.[16] Between 2000 and 2015, we observe a substantial reduction in all our outcome variables: -25.7% for energy consumption, -22.7% for employment and -29.4% for CO2 emissions.[17] The large increase in energy prices (56.1% in the estimation sample) is particularly concentrated in establishments of single-establishment firms, in sectors with low energy intensity and in trade exposed sectors. Note that the predicted increase in energy prices due to an ambitious carbon tax of 56 euro per ton of CO2 is, on average, similar to the historical one (i.e. 67.8% of energy prices in 2015), but would be substantially larger for establishments which use carbon-intensive energy sources such as those in energy-intensive sector.

When considering the whole estimation sample, historical changes in energy prices (Panel A) entirely explain the actual reduction in energy use (109%), while the induced reduction in CO2 emissions would have been twice larger (216%). In turn, only one quarter of the actual reduction in employment (21%) is accounted for by the historical increase in energy prices. The changes predicted by the carbon tax are proportionally larger (Panel B). Overall, the trade off between the emission reductions and job destruction is moderate: a 10% benefit in terms CO2 emissions will bring a cost in terms of job losses of only 0.74%.

However, the jobs vs. the environment trade-off becomes starker in specific sub-samples. Heterogeneous effects are driven here by the combination of differences in estimated elasticities

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[16] Average energy prices to compute historical changes and price level in 2015 and average CO2 intensity of energy (2015) are computed as the weighted average (sampling weights times energy use) for the selected estimation sample. Effects are aggregated across establishments included in the 2015 sample using uniform weights. Results based on alternative weighing methods are similar and available upon request.

[17] These figures refer to the full representative sample of establishments, weighted with sampling weights.

and differences in CO2 intensity of the energy mix. The 56-euro carbon tax would cost 5.8% of manufacturing jobs on average, but 8.3% in energy-intensive sectors and 9.8% in multi-establishment firms. The job destruction effect becomes significantly larger in the long-run (9.1%) compared to the short-run (4.4%). In summary, the risk of substantial job losses in the long-term, especially for certain industries, is real and should be factored into the design of an appropriate policy mix.

As a final note, the effect of the carbon tax on workforce skills is small, which is consistent with the statistically insignificant elasticities for three of the four skill groups. The carbon tax would entail an increase in the demand for technicians of 1.7% and a (nearly significant) decrease in the share of manual workers of 2.3%. These numbers are significantly lower than those found by Marin and Vona (2019) for EU sectors. One reason is that our estimates do not account for the across-firm reallocation favouring firms that employ a higher shares of technicians and professionals. Alternatively, this small effect can hide a bottleneck in the capacity of France to create the skills suitable for the low carbon transition, an issue worthy of exploration in future research.

4.4 Competitiveness impacts

In this section, we examine firm-level impacts. In doing so, we can study direct proxies of competitiveness, such as various productivity indicators. This extension allows us to directly test the strong Porter hypothesis and to understand the full set of trade-offs associated with future carbon pricing policies.

Given that energy-related information is available only for a sample of establishments, we retain those firm/year pairs (including single-establishment firms) for which all establishments were surveyed in the EACEI.[18] We consider three indicators of productivity: the log of sales per FTE employee, the log of gross value added (VA) per FTE employee and the log of total

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[18] As a robustness check, we also repeat our analysis by including those firms observed in EACEI establishments that accounted for at least 95 or, alternatively, 90% of total employees in the firm. The results were confirmed and are available upon request.

factor productivity (TFP), which is the closest proxy of the firm's level of input efficiency. We estimated TFP using the semiparametric estimator proposed by Levinsohn and Petrin (2003). TFP was estimated for the universe of firms by combining information about employment level from DADS and value added and capital (built with the perpetual inventory method with sector-specific depreciation) from FICUS/FARE.

[Table 10 about here]

The results are shown in Table 10. First, we find that higher energy prices have a modest negative effect on the two main measures of competitiveness, i.e., VA per worker and TFP. The estimated changes predicted by a price increase of 10% are about -1.4% for VA per worker and -1.7% for TFP and are smaller than those estimated in the related paper by Greenstone et al. (2012), who also use firm-level data but for a command-and-control-policy (the US Clean Air Act). This finding is also in line with recent evidence about the impact of the EU-ETS on firm performance (see e.g. Marin et al., 2018; Dechezleprêtre et al., 2018).[19] Overall, our analysis does not lend support to the strong Porter Hypothesis advocating the use of environmental policies to increase competitiveness, but suggests that market-based instruments (e.g., energy prices in our case) are less harmful for efficiency than command-and-control ones. However, we also find that the effect of energy prices on sales per workers is positive and statistically significant. The comparison of the effects of energy prices on sales per employee and on value added per employee indicates that, to mitigate the negative impact of energy prices on the average economic value (value added) per employee, firms need to increase their sales per worker by, for example, increasing their markups.

4.5 Within-firm input reallocation and exit

Our analysis focuses on the estimation of the causal effect of energy price on establishment-level performance with no consideration of compositional shifts induced by energy price shocks, such

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[19] Aldy and Pizer (2015) find similar negative but relatively modest effects of energy prices on production and net import for a panel of US manufacturing sectors.

as across-establishment reallocation effects and exit. However, these compositional effects are important for understanding the relevance of micro-level impacts at a more aggregate level, where policy makers usually assess the costs and benefits of specific policies (Smith, 2015).

Compositional changes are difficult to be captured in reduced-form regressions, but the richness of our data allow to examine two aspects of those changes: within-firm across-establishment reallocation and exit.

Within-firm input reallocation is the first level of reallocation that a manager would consider because moving production from an establishment to another one within the same firm and country is considerably easier than moving production to another firm and country.[20] In contrast to single-establishment firms, multi-establishment firms have a larger and more resilient internal input markets, as they have the possibility of choosing the quantity produced by each establishment in response to, among other factors, differences in input prices across establishments. This margin of adjustment for multi-establishment firms mitigates the effect of the price shock at the more aggregated firm-level, while it implies a larger response to price shocks within each establishment.

Fortunately, our data display enough between-establishment within-firm variation in energy prices to estimate this reallocation effect for a specific sub-sample of firms that are fully observed in the EACEI survey (but excluding single-establishment firms).[21] To illustrate, the within-firm across-establishments standard deviation in log energy prices (0.144), which is the source of variation that we exploit to estimate the reallocation effect, is still quite large compared to the average between-establishments standard deviation for the same sub-sample of multi-establishments firms (0.344). To assess within-firm reallocation, we add firm-year fixed effects

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[20] Wagner et al. (2014) consider within-firm carbon leakage as a consequence of the EU ETS using French data, finding little evidence, while Cestone et al. (2016) study labour reallocation across French firms belonging to the same business group and thus at a higher level than ours.

[21] In single-establishment firms, there is no scope for input reallocation. The sub-sample used in this analysis comprises the firms that satisfy the following conditions: i. all establishments of the firm were surveyed in EACEI in year t; ii. the establishments are observed at least two times in the period of 2000-2015; and iii. there is an additional observation for the establishment at least three years before the second observation (to be able to build the IV). By applying these criteria, we rely on an unbalanced panel of 1676 establishments that belong to 611 firms.

to our main estimation equation 2. Conditioning on on the year-firm fixed effect is equivalent to identify price effects only through differences between establishment- and firm-level prices.

[Table 11 about here]

The results are reported in Table 11. For sake of comparison, we also show our baseline estimates of equation 2 for the same selected sample (columns 2 and 4).[22] For both inputs, the absolute value of the estimated elasticity when allowing for within-firm reallocation of inputs (columns 1 and 3) is approximately twice as large as the estimated elasticity when within-firm reallocation is not considered (columns 2 and 4). Note, however, that employment impacts are more than four times larger in this sub-sample compared to the estimation sample used to derive the main results of Table 3. This sheds light on the different results on multi- vs. single-establishment firms. While an energy price shock had larger effect on the latter than on the former, input reallocation across establishment partly mitigates such larger effect.

Rather than adjusting inputs and output in response to changing energy prices, firms could opt for shutting down a specific establishment (multi-establishment firms) or leave the market altogether (single-establishment firms). The impact of exit on aggregated environmental and socioeconomic outcomes is ambiguous combining a substitution and a scale effect. The impact depends on the relative input intensity of the exiting establishment compared to that of surviving (or new) establishments that increase their market share as a consequence of exit of rivals. However, if, as it is plausible, higher energy prices deter entry and favour exit, the scale effect is likely to exacerbates reductions in energy, CO2 emissions and labour demand at the aggregate level.

Following Martin et al. (2014), we estimate the impact of energy prices on the probability of exit using a probit model, where our dependent variable is a dummy equals to one if the establish-

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[22] A caveat is important at this point: the results should be interpreted with particular care, as these conditions imply a non-random selection of establishments, further reducing the representativeness of the selected sample. Compared to the average establishment in the full sample, these establishments are 26.9% larger in terms of number of employees and report an energy consumption that is 97.2% larger.

ment closes at time t.[23] As exit is one-shot event, we cannot account for establishment-specific fixed effects. We control for establishment-specific heterogeneity using observable covariates measured before the establishment enters in the estimation sample (i.e. in the same year in which the energy mix is measured in our instrumental variable). These covariates are proxies of establishment's size (employment and energy use, both in log) as well as of firm-level characteristics (total sales and fixed capital stock per employee, both in log). As in our favourite specification, we account for year-sector (2-digit NACE) and year-region (NUTS2) fixed effects.

[Table 12 about here]

Results are shown in Table 12. In addition to our baseline specification (columns 1 and 2), we also estimate a more demanding specification in which the pre-sample variables are interacted with time dummies (columns 3 and 4). Overall, results highlight a positive effect of energy prices on the probability of exit, both in the probit and in the IV-probit models.[24] To quantify the contribution of energy prices to exit, we compute marginal effects at the average energy price and evaluate the predicted increase in exit probability of driven by historical price changes or by the French carbon tax. For the most demanding specification (column 4) we estimate an increase in probability of about 0.33% for historical changes in energy prices and of about 0.4% for a 56 euro carbon tax. These effects should be compared with an average annual exit rate of 4.3% for our estimation sample, which means that historical changes in energy prices explain about 7.7%-7.9% of exit over the same period.

This result suggests that the overall negative impact of energy prices on energy use, CO2 emissions and employment as estimated in our baseline regressions on the selected sample of

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[23] The EACEI data on energy use and prices for year t are collected by means of a annual survey that takes places in the first half of year $t+1$. This means that establishments that left the market between the beginning of year t and June of year $t+1$ are still active on the market in year t while data on energy use and prices will not be available. For this reason, our dummy variable for exit of establishment i in year t is set to one for establishments that left the market either in year $t+1$ or in year $t+2$. Exit of establishment i in year t is defined by looking at whether establishment i is reported in the list of active establishments in year t in the DADS database, that considers the universe of active French establishments. As we need information on exit in year t and $t+1$ and DADS data are available until year 2015, the estimation sample only runs from 2000 to 2013.

[24] This result holds when considering long-term impact adding lagged terms of energy prices (available upon request).

surviving establishments represents a lower bound of the true overall impact since it disregards the impact of energy prices on the extensive margin.

5 Conclusions

Our paper provides new evidence on the link between energy prices and various measures of economic and environmental performance for a panel of French manufacturing establishments. As a preliminary step in our analysis, we document the substantial cross-establishments heterogeneity in energy prices across sectors and establishments as well as large increases in energy prices accompanied by moderate decreases in quantity discounts for large energy consumers. We then evaluate the impact of energy prices on establishment's environmental and economics performance in a scenario that replicates what would happen following the adoption of ambitious carbon pricing policies. In doing so, we propose a shift-share instrumental variable approach suited to dealing with the potential endogeneity of energy prices.

Our results identify a trade-off between environmental and economic goals due to changing energy prices. We estimate that a 10-percent increase in establishment-level energy prices brings a 5% reduction in energy consumption and an 11% reduction in CO2 emissions. The same 10-percent increase in energy prices has a modest negative impact on employment (-0.8%) and total factor productivity (-1.7%) and an even smaller effect on wages (-0.09% but not significant). Importantly, we also find that short-term estimates are approximately two times smaller than the long(er)-term (3-years) effects for energy use, CO2 and employment. The negative employment effect differs across sectors and occupations. Reassuringly, the negative employment effects do not disproportionately affect the least skilled workers and are biased in favour of middle-skill technical competencies. Simulating the effect of the introduction of a 56 euro per ton of CO2 tax, we show that the trade-off between environmental goals and job losses is further amplified for energy-intensive and trade-exposed sectors because the former are relatively carbon intensive relative to the average, while the latter cannot pass through higher energy prices to their customers. In the absence of compensating labour market policies, such amplified job losses may fuel strong opposition by both industrial and workers' associations against carbon pricing policies.

Our reduced-form approach focuses on only one dimension of the impact of environmental regulation on environmental and economic performance, as we do not consider the consequences of entry and exit dynamics and of the reallocation of production (and, consequently, inputs) across establishments. We perform two additional exercises to give an idea of the direction of these compositional shifts by estimating energy price impacts on exit probability and on input reallocation within multi-establishments firms. We show that employment effects are mitigated by labour reallocation across establishments within the same firm, while the positive effect of energy prices on the probability of exit might suggest that our estimates represent a lower-bound of the true effect. This preliminary results on compositional effects are suggestive of the possible link between micro and macro effects, thus further research is required to incorporate these micro-estimates into a general equilibrium framework.

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Tables and figures

Table 1: Correlation in yearly changes in (log) national average energy prices for different inputs

	1	2	3	4	5	6	7	8	9	10	11	12
1 Average	1											
2 Natural gas	0.71	1										
3 Electricity	0.46	0.01	1									
4 Oil	0.61	0.33	0.14	1								
5 Butane-propane	0.67	0.60	-0.10	0.54	1							
6 Heating oil	0.54	0.40	0.21	0.31	0.82	1						
7 Other gas	0.66	0.78	-0.01	0.48	0.81	0.60	1					
8 Lignite	0.40	0.10	0.42	0.37	-0.04	0.02	0.01	1				
9 Coke	0.32	0.04	-0.02	0.58	0.34	0.14	0.16	0.12	1			
10 Coke-petroleum	0.57	0.51	-0.14	0.39	0.57	0.27	0.52	-0.11	0.24	1		
11 Steam	0.80	0.88	0.14	0.42	0.74	0.60	0.81	0.17	0.08	0.45	1	
12 Heavy oil	0.67	0.63	-0.07	0.51	0.94	0.78	0.82	-0.07	0.12	0.61	0.79	1

Notes: aggregate year- and input-specific prices are computed as the weighted average of establishment prices, using sampling weights times energy use as weights.

Table 2: Sector-level descriptive statistics

Sector		Energy exp / VA	Average energy price per kWh	Average electr price per kWh	Average gas price per kWh	Average electr share	Average gas share
13	Textiles	0.090	0.037	0.058	0.026	0.366	0.503
		(0.113)	(0.016)	(0.016)	(0.010)	(0.283)	(0.353)
14	Wearing apparel	0.020	0.045	0.068	0.029	0.389	0.472
		(0.028)	(0.018)	(0.021)	(0.012)	(0.239)	(0.328)
15	Leather and related products	0.015	0.050	0.072	0.035	0.422	0.281
		(0.027)	(0.019)	(0.018)	(0.013)	(0.243)	(0.307)
16	Wood and of products of wood and cork	0.078	0.046	0.060	0.026	0.543	0.342
		(0.015)	(0.020)	(0.022)	(0.011)	(0.282)	(0.321)
17	Paper and paper products	0.021	0.030	0.047	0.023	0.329	0.424
		(0.030)	(0.011)	(0.013)	(0.090)	(0.203)	(0.326)
18	Printing and reproduction of recorded media	0.045	0.048	0.062	0.029	0.545	0.383
		(0.059)	(0.017)	(0.017)	(0.011)	(0.235)	(0.256)
20	Chemicals and chemical products	0.243	0.028	0.044	0.021	0.194	0.399
		(0.590)	(0.013)	(0.014)	(0.010)	(0.216)	(0.378)
21	Basic pharmaceutical products	0.305	0.041	0.057	0.029	0.444	0.429
		(0.469)	(0.013)	(0.014)	(0.010)	(0.149)	(0.236)
22	Rubber and plastic products	0.062	0.046	0.058	0.026	0.584	0.305
		(0.068)	(0.019)	(0.019)	(0.013)	(0.308)	(0.311)
23	Other non-metallic mineral products	0.192	0.026	0.051	0.024	0.193	0.415
		(0.207)	(0.016)	(0.015)	(0.008)	(0.150)	(0.367)
24	Basic metals	0.350	0.021	0.040	0.024	0.203	0.141
		(0.542)	(0.012)	(0.015)	(0.009)	(0.248)	(0.223)
25	Fabricated metal products	0.044	0.048	0.064	0.030	0.490	0.411
		(0.059)	(0.018)	(0.020)	(0.012)	(0.252)	(0.290)
26	Computer, electronic and optical products	0.019	0.049	0.054	0.033	0.758	0.203
		(0.035)	(0.015)	(0.018)	(0.013)	(0.171)	(0.165)
27	Electrical equipment	0.032	0.045	0.057	0.029	0.519	0.331
		(0.076)	(0.014)	(0.016)	(0.011)	(0.232)	(0.254)
28	Machinery and equipment n.e.c.	0.024	0.049	0.065	0.032	0.474	0.436
		(0.040)	(0.017)	(0.022)	(0.012)	(0.211)	(0.249)
29	Motor vehicles, trailers and semi-trailers	0.034	0.043	0.056	0.028	0.532	0.394
		(0.041)	(0.014)	(0.015)	(0.012)	(0.212)	(0.232)
30	Other transport equipment	0.017	0.045	0.061	0.031	0.468	0.456
		(0.026)	(0.016)	(0.017)	(0.013)	(0.183)	(0.207)
31	Furniture	0.039	0.054	0.070	0.032	0.527	0.328
		(0.047)	(0.019)	(0.018)	(0.012)	(0.309)	(0.347)
32	Other manufacturing	0.022	0.051	0.064	0.033	0.587	0.340
		(0.023)	(0.016)	(0.016)	(0.013)	(0.216)	(0.235)
33	Repair and installation of M&E	0.014	0.056	0.075	0.036	0.469	0.361
		(0.032)	(0.021)	(0.024)	(0.014)	(0.278)	(0.321)
	Total	0.085	0.029	0.050	0.024	0.272	0.321
		(0.253)	(0.016)	(0.018)	(0.010)	(0.261)	(0.336)

Notes: Energy Standard deviations are given in parentheses. The results are our own elaboration on EACEI and DADS data. The information refers to the period of 1997-2015. Energy exp / VA is weighted by sampling weights × value added; Average energy price per kWh, Average electr share and Average gas share are weighted by energy consumption × sampling weights; Average energy price per kWh is weighted by electricity consumption × sampling weights; Average gas price per kWh is weighted by gas consumption × sampling weights.

Table 3: Effect of energy prices: baseline results

	Light specification		Favourite specification		Additional controls	
	FE	IV-FE	FE	IV-FE	FE	IV-FE
Energy consumption (kWh, in log)	-1.178*** (0.0238)	-0.450*** (0.0642)	-1.183*** (0.0239)	-0.500*** (0.0677)	-1.184*** (0.0242)	-0.535*** (0.0680)
CO2 emissions from energy use (tons, in log)	-1.645*** (0.0392)	-0.985*** (0.106)	-1.656*** (0.0393)	-1.133*** (0.111)	-1.665*** (0.0398)	-1.152*** (0.108)
Full-time equivalent employment (in log)	-0.0706*** (0.0105)	-0.0576 (0.0428)	-0.0738*** (0.0104)	-0.0837* (0.0451)	-0.0574*** (0.0103)	-0.0782* (0.0450)
Average wage per emplyee FTE (euro, in log)	-0.0000861 (0.00289)	-0.0169 (0.0161)	0.000498 (0.00290)	-0.00853 (0.0175)	0.000822 (0.00291)	-0.00874 (0.0176)
Region (NUTS2) × year dummies	x	x	x	x	x	x
Sector (NACE 2-digit) × year dummies			x	x	x	x
Additional controls (see notes)					x	x
F-test of excluded IV (energy, FTE, wages)		1362.3		1235.6		1242.8
F-test of excluded IV (CO2)		1070.9		965.2		1025.8

Notes: Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 88160 (78378 for CO2). N of establishments: 13403 (11864 for CO2). Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IV: log of national energy prices (by fuel) weighted with initial energy mix of the establishment. Additional control variables in columns 5-6: year-ETS dummies, year-peak (>Q3) dummies, year-size (initial size classes) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the establishment.

Table 4: Effect of lagged energy prices

Panel A - Regressions with two lags of energy price

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per emplyee FTE (euro, in log)
$\log(p_t^E)$	0.0572	-0.367**	0.0157	-0.0379
	(0.108)	(0.159)	(0.0698)	(0.0247)
$\log(p_{t-1}^E)$	-0.386***	-0.637***	-0.0491	0.00527
	(0.138)	(0.188)	(0.0824)	(0.0301)
$\log(p_{t-2}^E)$	-0.173*	-0.313**	-0.0939	0.00305
	(0.104)	(0.145)	(0.0593)	(0.0204)
Cumulative effect	-0.502***	-1.317***	-0.127*	-0.0296
	(0.105)	(0.172)	(0.0692)	(0.0236)

Panel B - Regressions with no lag of energy price for the same sample as in Panel A

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per emplyee FTE (euro, in log)
$\log(p^E)$	-0.253***	-0.858***	-0.0607	-0.0333*
	(0.0843)	(0.136)	(0.0585)	(0.0202)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 51528 (47428 for CO2). N of establishments: 8023 (7161 for CO2) F test of excluded IV in Panel A: 97.14 (98.44 for CO2). F test of excluded IV in Panel B: 737.7 (641 for CO2). Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IVs: log of national energy prices (by energy input) weighted with initial energy mix of the establishment.

Table 5: Effect of energy prices on workforce skills

	Share of engineers and managers	Share of technicians	Share of manual workers (high skills)	Share of manual workers (low skills)
$\log(p^E)$	-0.00263	0.0117*	0.0184	-0.0232
	(0.00620)	(0.00676)	(0.0175)	(0.0164)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 88160. N of establishments: 13403. F test of excluded IV: 1235.6. Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the establishment.

Table 6: Effect of energy prices by sectoral energy intensity

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per FTE (euro, in log)
$\log(p^E)$	-0.462***	-1.089***	-0.0589	0.000530
	(0.0743)	(0.119)	(0.0482)	(0.0189)
$\log(p^E)$ x Energy intensity	-0.201**	-0.217	-0.132**	-0.0480**
	(0.0853)	(0.135)	(0.0629)	(0.0229)
Net effect at the first decile of energy intensity	-0.466***	-1.093***	-0.0614	-0.000393
	(0.0735)	(0.118)	(0.0477)	(0.0187)
Net effect at the tenth decile of energy intensity	-0.510***	-1.144***	-0.0901**	-0.0109
	(0.0665)	(0.110)	(0.0447)	(0.0173)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 88160 (78378 for CO2). N of establishments: 13403 (11864 for CO2). F test of excluded IVs: 614.7 (481 for CO2). Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IVs: i) log of national energy prices (by energy input) weighted with initial energy mix of the establishment; ii) log of national energy prices (by energy input) weighted with initial energy mix of the establishment interacted with pre-sample (1997-1999) average energy intensity (energy expenditure share of VA) of the 3-digit sector.

Table 7: Effect of energy prices by sectoral trade exposure

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per FTE (euro, in log)
$\log(p^E)$	-0.475***	-1.110***	-0.0611	-0.0116
	(0.0704)	(0.114)	(0.0452)	(0.0180)
$\log(p^E)$ x Trade exposed sector (dummy)	-0.0599**	-0.0544	-0.0527**	0.00708
	(0.0279)	(0.0406)	(0.0212)	(0.00699)
Net effect with Trade exposed sector dummy = 1	-0.535***	-1.164***	-0.114**	-0.00449
	(0.0674)	(0.111)	(0.0476)	(0.0175)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 88160 (78378 for CO2). N of establishments: 13403 (11864 for CO2). F test of excluded IVs: 612.1 (478.7 for CO2). Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IVs: i) log of national energy prices (by energy input) weighted with initial energy mix of the establishment; ii) log of national energy prices (by energy input) weighted with initial energy mix of the establishment interacted with trade exposed sector dummy.

Table 8: Effect of energy prices: single-establishment vs multi-establishments firms

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per FTE (euro, in log)
$\log(p^E)$	-0.434***	-1.080***	-0.0463	-0.0233
	(0.0710)	(0.115)	(0.0476)	(0.0181)
$\log(p^E)$ x Multi-establishment	-0.131***	-0.110***	-0.0726***	0.0268***
dummy	(0.0187)	(0.0278)	(0.0142)	(0.00449)
Multi-establishment dummy	-0.325***	-0.285***	-0.187***	0.0804***
	(0.0558)	(0.0836)	(0.0415)	(0.0132)
Net effect with Multi-establishment	-0.565***	-1.190***	-0.119***	0.00359
dummy = 1	(0.0658)	(0.108)	(0.0437)	(0.0172)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 88160 (78378 for CO2). N of establishments: 13403 (11864 for CO2). F test of excluded IVs: 613.9 (483.9 for CO2). Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IVs: i) log of national energy prices (by energy input) weighted with initial energy mix of the establishment; ii) log of national energy prices (by energy input) weighted with multi-plant dummy.

Table 9: Quantification of estimated effects

Panel A - Historical increase in energy prices 2000-2015					
	Predicted change in energy price $\frac{p^E_{2015}-p^E_{2000}}{p^E_{2000}}$	Predicted change of energy consumption w.r.t. 2015	Predicted change of CO2 emissions w.r.t. 2015	Predicted change of full-time equivalent employment w.r.t. 2015	Predicted change of average wage per employee FTE w.r.t. 2015
Average	0.561	-0.280	-0.635	-0.047	-0.005
Single-establishment firms	0.832	-0.361	-0.898	-0.039	-0.019
Multi-establishments firms	0.455	-0.257	-0.542	-0.054	0.002
Top decile of energy intensity	0.468	-0.239	-0.535	-0.042	-0.005
Bottom decile of energy intensity	0.839	-0.391	-0.917	-0.052	0.000
Trade exposed sectors	0.707	-0.378	-0.822	-0.081	-0.003
Non-trade exposed sectors	0.583	-0.277	-0.648	-0.036	-0.007
Long run effect	0.514	-0.258	-0.677	-0.065	-0.015
Short run effect	0.514	-0.130	-0.441	-0.031	-0.017
Panel B - Carbon tax of 56 euro per ton of CO2					
	Predicted change in energy price $\triangle\hat{p}^E/p^E_{2015}$	Predicted change of energy consumption w.r.t. 2015	Predicted change of CO2 emissions w.r.t. 2015	Predicted change of full-time equivalent employment w.r.t. 2015	Predicted change of average wage per employee FTE w.r.t. 2015
Average	0.678	-0.339	-0.768	-0.057	-0.006
Single-establishment firms	0.402	-0.175	-0.434	-0.019	-0.009
Multi-establishments firms	0.822	-0.465	-0.979	-0.098	0.003
Top decile of energy intensity	0.916	-0.467	-1.048	-0.083	-0.010
Bottom decile of energy intensity	0.166	-0.077	-0.181	-0.010	0.000
Trade exposed sectors	0.535	-0.286	-0.623	-0.061	-0.002
Non-trade exposed sectors	0.799	-0.380	-0.887	-0.049	-0.009
Long run effect	0.718	-0.360	-0.945	-0.091	-0.021
Short run effect	0.718	-0.182	-0.616	-0.044	-0.024

Notes: IV-FE elasticities used to build the counterfactual: 'average' Table 3, Panel B; 'energy intensity' Table 6; 'trade' Table 7; 'multi-establishments' Table 8; 'long run' Table 4, Panel A; 'short run' Table 4, Panel B. Average price in 2015 and average CO2 intensity of energy is computed as the weighted average (using sampling weights times energy use) for the establishments in the estimation sample. Sample-specific change in energy prices is calculated using average energy prices weighted using sampling weights times energy use on the estimation sample.

Table 10: Results for firm-level measures

	Value added per employee FTE (euro, in log)	Total factor productivity (in log)	Sales per employee FTE (euro, in log)
$\log(p^E)$	-0.142* (0.0824)	-0.175** (0.0801)	0.132** (0.0627)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: Value added per employee, 46262 (7913 firms); TFP, 40066 (7290 firms); Sales per employees, 46580 (7956 firms). F test of excluded IV: Value added per employee, 660.9; TFP, 610.3; Sales per employee, 664.3. Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the firm. Sample: firms for which all establishments are included in EACEI and that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV).

Table 11: Within-firm reallocation of inputs

	Energy consumption (kWh, in log)		Full-time equivalent employment (in log)	
	Within-firm reallocation (firm-year dummies)	Baseline specification for the same sample	Within-firm reallocation (firm-year dummies)	Baseline specification for the same sample
$\log(p^E)$	-1.038*** (0.379)	-0.451** (0.187)	-0.582* (0.325)	-0.286* (0.158)

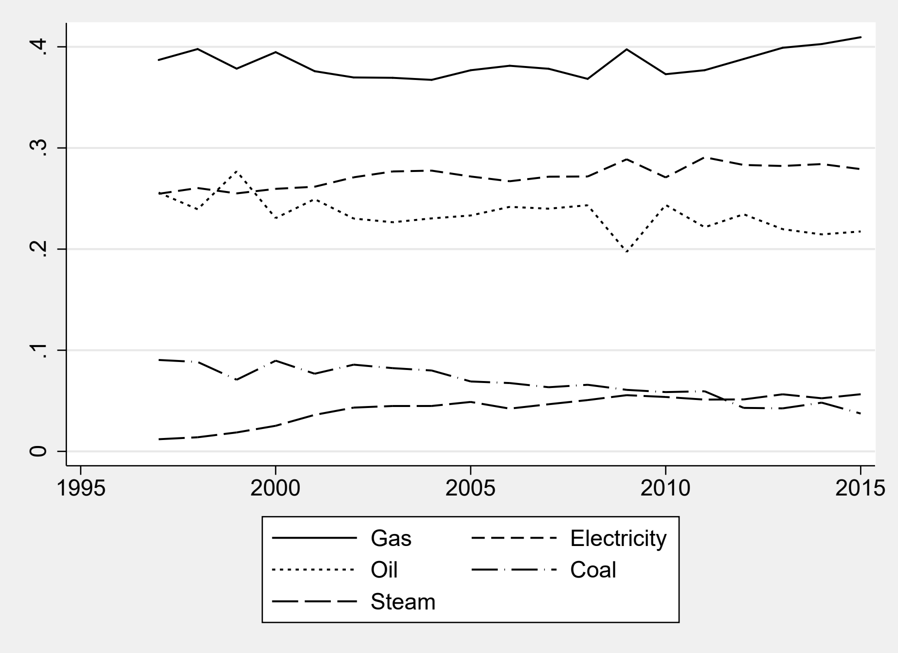
Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 6782. N of establishments: 1676. N of firms: 611. F test of excluded IV: 43.44 for the within-firm reallocation specification (columns 1 and 3); 94.47 for the baseline specification (columns 2 and 4). Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the establishment. Additional control variables: region-year dummies; sector-year dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV).

Table 12: Effect on establishments' exit

Dep variable: exit	Probit	IV-Probit	Probit	IV-Probit
$\log(p^E)$	0.0838** (0.0411)	0.210** (0.0979)	0.118*** (0.0424)	0.235** (0.101)
Control variables (employment, energy consumption, firm-level capital stock per employee, firm-level sales)	Pre-sample levels	Pre-sample levels	Pre-sample levels interacted with year dummies	Pre-sample levels interacted with year dummies

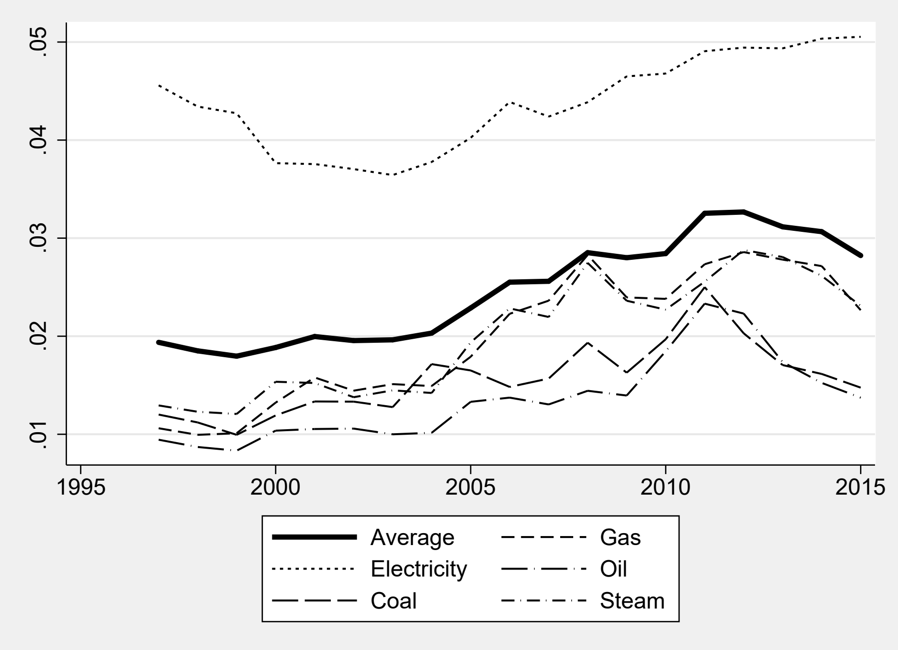
Notes: Standard errors clustered by establishment in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. The dependent variable is dummy equal to 1 if the establishment left the market either in year t+1 or t+2. If present, observations in year t+1 and t+2 were removed from the estimation sample. N of observations: 70588. N of establishments: 11893. Additional control variables in all regressions: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the establishment.

Figure 1: Average energy mix of the French manufacturing sector



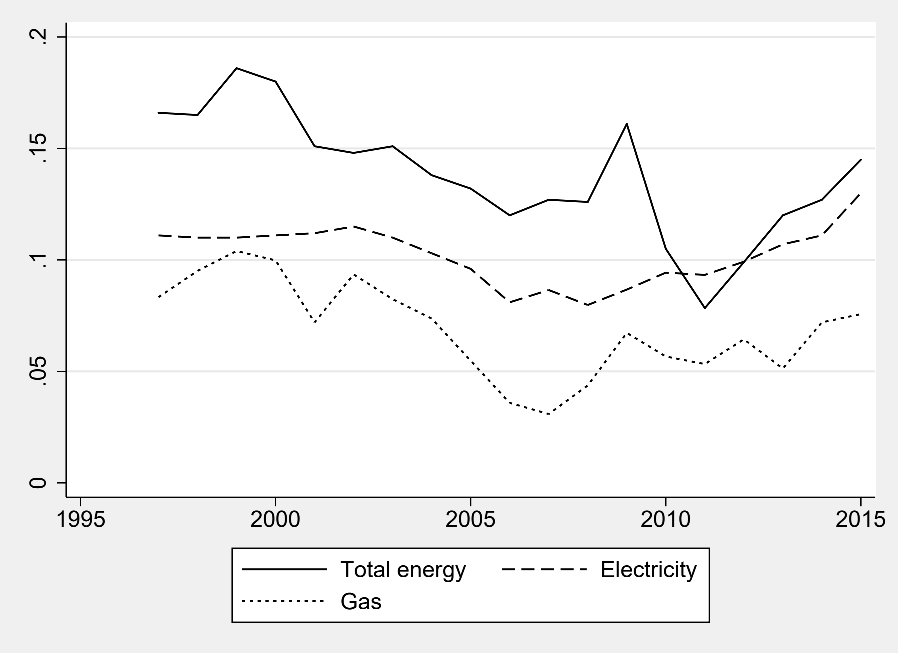
Notes: The results are our own elaboration on EACEI data. The average energy mix is weighted by sampling weights multiplied by energy consumption. Gas: natural gas, butane-propane, other gas. Oil: oil, heating oil, heavy oil. Coal: lignite, coke, coke-petroleum.

Figure 2: Average energy prices of French manufacturing establishments



Notes: The results are our own elaboration on EACEI data. Average energy prices, deflated to 1997 prices by means of the French GDP deflator, are weighted by sampling multiplied by energy consumption. Gas: natural gas, butane-propane, other gas. Oil: oil, heating oil, heavy oil. Coal: lignite, coke, coke-petroleum.

Figure 3: Quantity discount for energy (total and electricity)



Notes: The results are our own elaboration on EACEI data. The year-by-year elasticity (absolute value) of the energy price with respect to energy consumption is conditional on sector dummies (2-digit NACE) and region (NUTS2) dummies. Regressions are weighted by energy consumption multiplied by sampling weights.

APPENDICES (FOR ONLINE PUBLICATION ONLY)

A Data sources

A.1 EACEI Survey

The main source of data is the EACEI survey. EACEI (Enquête sur les consommations d'énergie dans l'industrie) is a survey of manufacturing establishments that provides information on energy consumption (quantity and value) broken down by energy type: electricity (consumed and autoproduced), steam, natural gas, other types of gas, coal, lignite, coke, propane, butane, heavy fuel oil, heating oil and other petroleum products. In the first part of our period (1997-2010), sectors 10-12 (Manufacture of food products, beverages and tobacco products, NACE Rev 2) were not included in the survey design, while the sector 19 (Manufacture of coke and refined petroleum products) is only included from year 2002 onwards. We thus exclude establishments in these sectors in the second part of our panel as well. From 2007 onwards, other nonmanufacturing industrial sectors were included (e.g., 38.3 'Material recovery'). We also exclude these additional nonmanufacturing sectors.[1] All establishments with more than 250 employees are requested to participate to the survey (see Wagner et al., 2014, for further details), while only a sample of establishments with 20 or more employees (stratified by nomenclature of activities (NTE) dedicated to energy consumption, workforce bands, and region) are interviewed.[2] The response rate is nearly 90%. In order to have a consistent sample of industries for the whole period that we consider (e.g. to compute national energy prices) we only consider establishments that belong to industries that were part of the survey design for all years between 1997 and 2015.

In our analysis, we only consider the consumption of energy that is purchased by the establishment. A relatively small share of establishments are equipped with one or more power generators to autoproduce electricity. The EACEI survey also provides information on the actual amount of electricity that is autogenerated. This electricity does not enter our measure of total energy use, as autogeneration employs other sources of energy (e.g., gas, coal) purchased and used as production inputs in the power generators. By not including autogenerated electricity, we avoid a double counting of energy.

To compute establishment-level CO2 emissions, we employ CO2 emission factors for the different energy sources from EIA (U.S. Energy Information Administration). In this way, we just consider 'direct' energy-related CO2 emissions released by each establishment, while implicit emissions released in the process of generating purchased electricity and steam are not considered in establishment-specific CO2 emissions. As a consequence, direct CO2 emissions of establishments relying just on electricity and/or steam are set to zero and the corresponding observations are not included in the sample used to estimate the impact of energy prices on CO2 emissions. According to our measure, changes in within-establishment CO2 emissions is the results of the combination in changes in the level of overall energy consumption and changes in the average CO2 intensity (time invariant source-specific CO2 emission factors) of the energy mix.

A.2 FICUS-FARE and DADS

Balance sheet information for French firms was retrieved from the FICUS (Fichier de comptabilité unifié dans SUSE, 1997-2007) and FARE (Fichier approché des résultats d'Esane 2008-2015) databases, which contain information on balance sheets and income statements for the universe of French firms. Firm-level data from FICUS/FARE were linked to EACEI and DADS based on the unique identifiers of French firms (SIREN).

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[1] Other relatively minor sectors were not included in the survey design of EACEI (classification NAF Rev. 2): 16.10A, 16.10B, 20.13A, 24.46Z.

[2] All establishments with 20 employees or more are surveyed for sectors 23.32Z, 23.51Z and 23.52Z (NAF Rev. 2 classification), while all establishments with 10 or more employees are interviewed for sector 20.11Z (NAF Rev. 2 classification

Information on establishment-level employment (measured in terms of full-time equivalent employees), total wages paid and average wages (per full-time equivalent employee) were retrieved from the DADS (Déclaration Annuelle des données Sociales) 'Postes' database, which is an administrative collection of data on employment and wages for the universe of French establishments. We linked information in EACEI with information in DADS by means of the unique identifiers of French establishments (SIRET).

For each employee we have information on the occupation according to the 2003 version of the PCS (Professions et catégories socioprofessionnelles des emplois salariés d'entreprise) classification at the 4-digit. Following Marin and Vona (2019), we identify four macro-occupational groups that reflect what Vona et al. (2018) define as 'Green skills', that is Engineering and Technical skills, Operation Management skills, Monitoring skills and Science skills. More specifically, we group together employees in occupations that require engineering, managerial (i.e. Operation Management) and scientific skills into an aggregate occupational group labelled 'Engineers and managers'. A second occupational group refers to occupations that require technical skills, that we label as 'Technicians'. As suggested by Vona et al. (2018), environmental regulatory stringency should be positively related with the demand for these skills. On the other hand, Marin and Vona (2019) suggest that the demand for manual skills might be negatively related to environmental regulatory stringency. To this purpose, we identify two occupational groups that contain occupations that require, respectively, high manual skills and low manual skills.

Table A1: Occupational classification based on the 2-digit PCS-2003 classification (Professions et catégories socioprofessionnelles des emplois salariés d'entreprise)

PCS code (2-digit)	Description (in French)
Engineers and managers	
23	Chefs d'entreprises industrielles ou commerciales de 10 salariés et plus
31	Professions libérales (exercées sous statut de salarié)
33	Cadres de la Fonction Publique
38	Ingénieurs et cadres techniques d'entreprises
Technicians	
47	Techniciens (sauf techniciens tertiaires)
Manual occupations (high skills)	
62	Ouvriers qualifiés de type industriel
63	Ouvriers qualifiés de type artisanal
Manual occupations (low skills)	
67	Ouvriers non qualifiés de type industriel
68	Ouvriers non qualifiés de type artisanal

The 2-digit PCS occupations allocated to the four macro occupational groups are reported in Table A1.[3] We do not consider clerical and service occupations as these occupations are likely to remain unaffected by environmental policy.

A.3 Trade exposed sectors

To identify trade-exposed sectors, we employ one of the criteria used by the European Commission to exempt from auctioning of allowances (from the third phase, 2013-2020) establishments in those sectors that were deemed to be at risk of carbon leakage (Decision 2010/2/EU, amended

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[3] We cannot exploit consistently the 4-digit detail of the PCS available in DADS 'Postes' as the occupational classification for years 2000-2002 (PCS-1982) is quite different at the 4-digit level from the occupational classification for years 2003-2015 (PCS-2003), while the concordance between PCS-1982 and PCS-2003 at the 2-digit level is perfect.

by the Decisions 2012/498/EU and 2014/9/EU). These criteria consider the CO2 emission intensity of the sector and its exposure to extra-EU28 trade. We identify trade-exposed sectors for which trade (import plus export) with non-EU28 countries is greater than 10% of the total EU28 production in that sector (see Table A2).[4].

Table A2: Trade exposed sectors (3-digit) based on the EU-ETS criterion for exemption from auctioning

	High trade intensity
13.1	Preparation and spinning of textile fibers
13.2	Weaving of textiles
13.9	Manufacture of other textiles
14.1	Manufacture of wearing apparel, except fur apparel
14.3	Manufacture of knitted and crocheted apparel
15.1	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness; dressing and dyeing of fur
20.1	Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic rubber in primary forms
20.2	Manufacture of pesticides and other agrochemical products
20.5	Manufacture of other chemical products
20.6	Manufacture of man-made fibers
21.1	Manufacture of basic pharmaceutical products
21.2	Manufacture of pharmaceutical preparations
22.1	Manufacture of rubber products
23.2	Manufacture of refractory products
23.4	Manufacture of other porcelain and ceramic products
24.2	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
24.4	Manufacture of basic precious and other nonferrous metals
25.4	Manufacture of weapons and ammunition
25.7	Manufacture of cutlery, tools and general hardware
26.1	Manufacture of electronic components and boards
26.2	Manufacture of computers and peripheral equipment
26.3	Manufacture of communication equipment
27.1	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
27.3	Manufacture of wiring and wiring devices
27.4	Manufacture of electric lighting equipment
27.5	Manufacture of domestic appliances
27.9	Manufacture of other electrical equipment
28.1	Manufacture of general-purpose machinery
28.2	Manufacture of other general-purpose machinery
28.3	Manufacture of agricultural and forestry machinery
28.4	Manufacture of metal forming machinery and machine tools
28.9	Manufacture of other special-purpose machinery
29.1	Manufacture of motor vehicles
30.1	Building of ships and boats
30.3	Manufacture of air and spacecraft and related machinery
30.9	Manufacture of transport equipment n.e.c.
32.2	Manufacture of musical instruments
32.3	Manufacture of sports goods
32.5	Manufacture of medical and dental instruments and supplies

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[4] The list is available at: https://ec.europa.eu/clima/policies/ets/allowances/leakage_en (last accessed: July 2017)

B Characteristics of the estimation sample

The characteristics of the estimation sample that we employed in our baseline results are reported in Table B1. Overall, the largest possible estimation sample for the period of 2000-2015 consists of 124,604 observations (establishment/year). Our estimation sample for total energy and employment includes 88,160 observations. These selected observations represent 70.75% of the total number of possible observations but account for as much as 81.2% of energy consumption and 77.8% of employment (see Table B1).

Table B1: Characteristics of the estimation sample

Potential number of observations (2000-2015)	124,604
'Selected' observations	88,160
Share of 'selected' observations	0.7075
Share of energy consumption in selected observations	0.8119
Share of labour in selected observations	0.7776

To gain a more precise understanding of the bias brought about by this sample selection, we regress a series of variables on a dummy variable that equals one for observations in the selected sample and zero otherwise. The results are reported in Table B2. Conditional on year dummies, selected establishments are larger in terms of employees , consume more energy and are more energy intensive in terms of energy consumption per employee. On average, conditioning on total energy consumption (to account for quantity discounts), energy prices were not statistically different between the selected and the full sample.

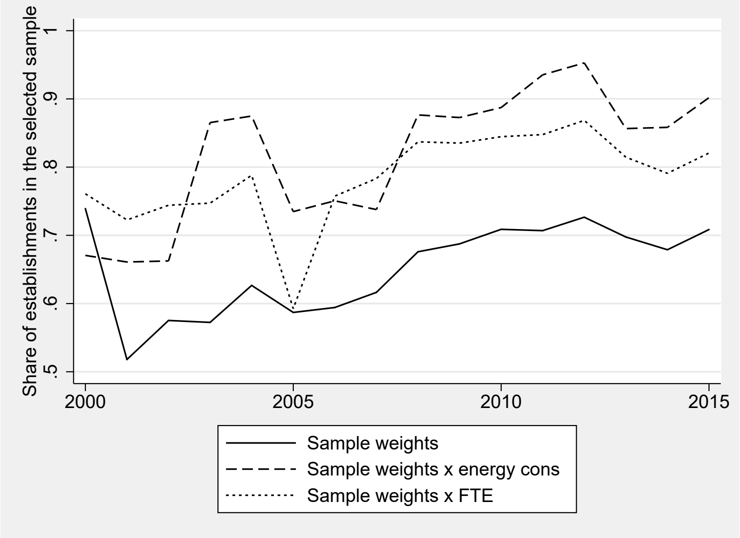
Table B2: Differences between estimation sample and overall population

Dep var	Full-time equivalent employment (in log)	Energy consumption (kWh, in log)	Energy consumption / FTE (in log)	$\log(p^E)$
Dummy: selected sample	0.691***	1.452***	0.760***	0.000416
	(0.00990)	(0.0218)	(0.0174)	(0.00296)
Energy consumption (kWh, in log)				-0.124***
				(0.000963)

Notes: OLS pooled model weighted with sampling weights. Year dummies are included. N of observations: 124604. Robust standard errors are in parentheses. * p<0.1, ** p<0.05, ***p<0.01.

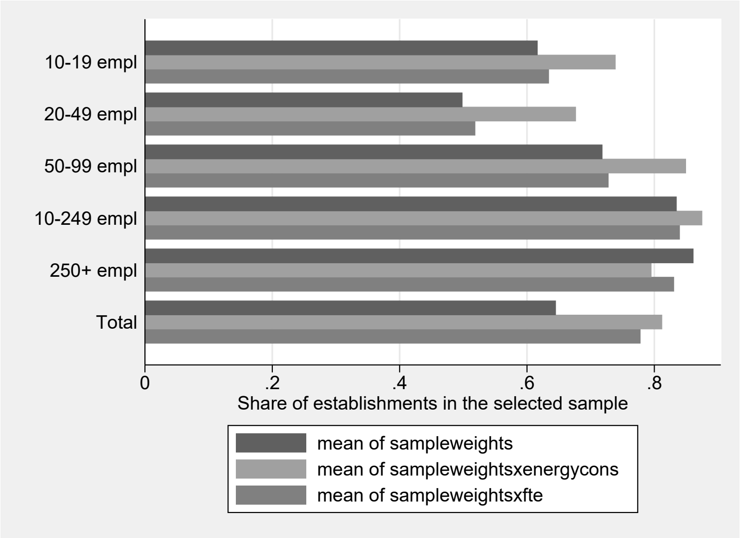
To have a sense of the possibility to generalize our results to the whole French manufacturing sector, we report the trend in the share of establishments (with different weights) included in the sample compared to the reference universe of establishments in the EACEI survey (Figure B1). As expected, the coverage is greater in more recent years due to the requirement to observe a lag in the energy mix (to build the IV) to be included in the selected sample. Moreover, the coverage when considering 'energy consumption' as weights is better than when considering FTE employment and substantially better than when considering simple sampling weights. To illustrate, for year 2012 (year in which we have the best coverage) we include in our selected sample 72% of establishments (sampling weights) that account for 86% of the FTE employment and as much as 95% of the energy consumption of all manufacturing establishments surveyed by EACEI in the same year.

Figure B1: Share of establishments in the selected sample by year



Finally, to further evaluate the representativeness of the the selected sample we consider the relative representativeness across different establishment size categories (Figure B2). Overall, the coverage appears to be systematically greater for medium-big establishments (50 or more employees), even though the trend is not monotonic across different size classes. Reassuringly, the coverage in terms of energy consumption is always above 70% across all size classes, above 54% for FTE employment and above 52% for simple sampling weights.

Figure B2: Share of establishments in the selected sample by establishment's size



C Testing for pre-trends

We explicitly test the validity of the exclusion restriction under the possibility that, due to some additional unobserved factors, establishments with different initial energy mixes exhibit different (pre-)trends in the outcome variable. If this was the case, our shift-share instrument could not disentangle the exogenous change in energy prices from pre-existing systematic differences in trends across firms with different initial mixes. In doing so, we estimate the differences in employment level (which is available in DADS for all establishments and all years) for establishments with different initial (1997) energy mixes up to 2001.[5] We detect pretreatment differences using the following equation:

$$\begin{aligned}\log(L_{it}) &= \alpha_i + \sum_{t=1998}^{2001} \beta_t^{j=gas} \phi_{i,t=1997}^{j=gas} + \sum_{t=1998}^{2001} \beta_t^{j=el} \phi_{i,t=1997}^{j=el} + \\ &+ X_{it}'\gamma + \epsilon_{it}\end{aligned}$$

where $\log(L_{it})$ is the logarithm of employment in establishment i and year t, α_i is the establishment fixed effect, X_{it} is the usual set of control variables, and ϵ_{it} is the error term. We focus on the two main sources, gas and electricity (which account, together, for about 60% of total energy consumption for French manufacturing establishment), allowing the effect of their initial shares $\phi_{i,t=1997}^{j}$ (with j referring either to gas or electricity) to vary over time.[6] To detect the existence of different pretreatment trends, we jointly test the null hypothesis that $\hat{\beta}_t^j$ are equal to zero.

The results are reported in Table C1. In column 1, we simply replace the vector X_{it} with year dummies. Moving from column 2 through column 4 we add control variables in line with Table 3: in column 2 we account for region-year dummies; in column 3 we account for region-year and sector-year dummies; in column 4 we account for region-year and sector-year dummies as well as for other flexible controls. Without accounting for the most demanding set of control variables, we observe that firms that relied more heavily on electricity in their energy mixes in 1997 grew significantly faster than firms with a smaller share of electricity. However, the F test of joint significance fails to accept the null hypothesis of common trends for establishments with different initial electricity share with $p<0.01$ only in columns 1 (year dummies) and 2 (region-year dummies). When also accounting for sector-year dummies (column 3) and other flexible controls (column 4), all F tests of joint significance suggest that conditional on controls, no difference in pre-trends is observed for firms with different initial energy mixes.

This result has two implications for our analysis. First, the reliance of our IV on a time-invariant energy mix does not bear the risk of capturing pre-existing differences across establishments that are connected with the energy mix itself. Second, accounting for sector-year dummies matters for the validity of our IV strategy.

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[5] We include only those establishments that were observed for all years in DADS between 1997 and 2001. Energy consumption and CO2 emissions cannot be evaluated here as these variables are available for all years between 1997 and 2001 only for a very small number of establishments, while data on employment from DADS are available for the population of French establishments active in all years.

[6] Since $\sum_{j=1}^{12} \phi^j = 1$ by definition, this is equivalent to treating the remaining sources as the omitted category.

Table C1: Differences in employment patterns for establishments with different initial energy mixes

Dep var: log(FTE)	(1)	(2)	(3)	(4)
Initial electricity share x D1998	0.0194	0.0189	0.00870	0.00276
	(0.0144)	(0.0143)	(0.0150)	(0.0152)
Initial electricity share x D1999	0.0230	0.0221	0.00859	-0.000688
	(0.0216)	(0.0217)	(0.0226)	(0.0227)
Initial electricity share x D2000	0.0838***	0.0825***	0.0494**	0.0299
	(0.0226)	(0.0225)	(0.0232)	(0.0237)
Initial electricity share x D2001	0.0888***	0.0885***	0.0670**	0.0459
	(0.0316)	(0.0316)	(0.0328)	(0.0333)
Initial gas share x D1998	0.00381	0.00242	-0.00340	0.00107
	(0.0140)	(0.0141)	(0.0146)	(0.0145)
Initial gas share x D1999	0.00148	0.00385	-0.00603	-0.00125
	(0.0197)	(0.0197)	(0.0200)	(0.0200)
Initial gas share x D2000	0.00399	0.00501	-0.0128	0.00907
	(0.0221)	(0.0221)	(0.0220)	(0.0221)
Initial gas share x D2001	0.00863	0.00770	-0.00647	0.00572
	(0.0307)	(0.0306)	(0.0307)	(0.0307)
Year dummies	Yes	-	-	-
Region - year dummies	-	Yes	Yes	Yes
Sector (2-digit) - year dummies	-	-	Yes	Yes
Additional controls	-	-	-	Yes
F test: joint significance of electr share	4.568	4.479	1.863	0.915
p-value	0.0011	0.00129	0.114	0.454
F test: joint significance of gas share	0.0360	0.0184	0.0983	0.149
p-value	0.998	0.999	0.983	0.964

Notes: Fixed effect model. Robust standard errors in parenthesis. * $p<0.1$, ** $p<0.05$, *** $p<0.01$. N of observations: 43745. N of establishments: 8749. Sample: establishment in EACEI 1997 that were observed in DADS in all years for the period 1997-2001. Gas includes natural gas, butane-propane, other gases.

D Robustness checks

In this section we show the tables of the robustness checks discussed at the end of Section 4.1.

Table D1: Results conditional on firm's sales

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per FTE (euro, in log)
log(p^E)	-0.498***	-1.142***	-0.117***	-0.00882
	(0.0660)	(0.109)	(0.0422)	(0.0175)
log(sales - firm)	0.246***	0.196***	0.347***	0.0143***
	(0.00991)	0.0110)	(0.00963)	(0.00316)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 87451 (77748 for CO2). N of establishments: 13295 (11769 for CO2). F test of excluded IV: 1228.3 (958.1 for CO2). Additional control variables: year-sector (2-digit NACE rev 2) and year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV). Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the establishment.

Table D2: Firm-level estimates for baseline outcome variables

Panel A - Firm-level analysis

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per emplyee FTE (euro, in log)
log(p^E)	-0.703***	-1.297***	-0.0820*	-0.00338
	(0.0905)	(0.152)	(0.0500)	(0.0176)

Panel B - Establishment-level analysis for the same sample of firms of Panel A

	Energy consumption (kWh, in log)	CO2 emissions from energy use (tons, in log)	Full-time equivalent employment (in log)	Average wage per emplyee FTE (euro, in log)
log(p^E)	-0.489***	-1.007***	-0.126**	-0.0149
	(0.0796)	(0.133)	(0.0498)	(0.0176)

Notes: FE-IV estimator. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations in Panel A: 46600 (40720 for CO2). N of firms in Panel A: 7939 (6966 for CO2). F test of excluded IV in Panel A: 711.4 (532.2 for CO2). N of observations in Panel B: 54965 (48201 for CO2). N of firms in Panel B: 9427 (8294 for CO2). F test of excluded IV in Panel B: 853.2 (661.1 for CO2). Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Excluded IV: log of national energy prices (by energy input) weighted with initial energy mix of the firm. Sample: firms for which all establishments are included in EACEI and that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV).

E First stages of the IV estimates

Table E1: First stage results (Tables 3 and 5, all dependent variables except CO2)

Dependent variable: $\log(p^E)$	Region-year dummies	Region-year dummies and sector-year dummies	Region-year dummies, sector-year dummies, additional control variables
IV	0.574*** (0.0145)	0.564*** (0.0150)	0.560*** (0.0150)

Notes: First stages of the IV estimate of for energy consumption, FTE and average wages. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 88160. N of establishments: 13403. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV).

Table E2: First stage results for the specification with lagged energy prices (Panel A of Table 4; all dependent variables, except CO2)

	$\log(p^E_t)$	$\log(p^E_{t-1})$	$\log(p^E_{t-2})$
IV_t	0.418***	0.0644***	.102***
	(0.0174)	(0.0169)	(0.0190)
IV_t	0.0831***	0.405***	0.0229
	(0.0202)	(0.0193)	(0.0196)
IV_t	-0.0135	0.0818***	0.509***
	(0.0191)	(0.0192)	(0.0200)

Notes: First stages of the IV estimate for Energy consumption, FTE and average wages. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. N of observations: 51528. N of establishments: 8023. Additional control variables: year-sector (2-digit NACE rev 2), year-region (NUTS2) dummies. Sample: establishments that are observed in EACEI for at least two years and observations three years or more after the first year in EACEI (used to build the initial energy mix for the IV).