CARBON OFFSHORING: EVIDENCE FROM FRENCH MANUFACTURING COMPANIES

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ABSTRACT

Concerns about carbon offshoring, namely the relocation of dirty tasks abroad, undermine the efficiency of domestic carbon mitigation policies and might prevent governments from adopting more ambitious climate policies. This paper is the first to analyse the extent and determinants of carbon offshoring at the firm level. We combine information on carbon emissions, imports, imported emissions and environmental policy stringency based on a unique dataset of 5,000 French manufacturing firms observed from 1997 to 2014. We estimate the impact of imported emissions on firm's domestic emissions and emission intensity using a shift-share instrumental variable strategy. We do not find compelling evidence of an impact of carbon offshoring on total emissions, but show that emission efficiency improves in companies offshoring emissions abroad, suggesting that offshored emissions are compensated by an increase in production scale. The effect is economically meaningful with a 10% increase in carbon offshoring causing a 4% decline in emission intensity. However, this effect is twice as small as that of domestic energy prices and, importantly, does not appear to be driven by a pollution haven motive.

KEYWORDS

Carbon offshoring, CO2 emissions, emissions intensity, import competition, energy prices

JEL

F1, F14, Q56.

Carbon Offshoring: Evidence from French Manufacturing Companies[*]

Damien Dussaux[†] Francesco Vona[‡] Antoine Dechezleprêtre[§]

Abstract

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Keywords: carbon offshoring, CO2 emissions, emissions intensity, import competition, energy prices

JEL: F18; F14; Q56

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1. Introduction

Climate change represents a global threat that will affect all regions in the world, and with the 2015 Paris Agreement, countries have agreed on the ambitious global target of limiting the global temperature increase to well below 2°C above pre-industrial levels. However, the level of ambition to reduce carbon emissions differs markedly across countries, as illustrated by the vast heterogeneity in Nationally Determined Contributions (Stephenson et al., 2019). In this interconnected but warming world, divergent ambitions on climate policies raise the concern that the introduction of ambitious policies in some countries or regions simply leads to a shift in emissions to less ambitious countries, following the so-called Pollution Haven Hypothesis (Taylor, 2004; Levinson and Taylor, 2008). The potential for carbon leakage can undermine the effectiveness of climate policies at reducing global greenhouse gas (GHG) emissions (Reguant and Fowlie, 2018) and has led the European Union to propose the introduction of a "Carbon Adjustment Mechanism" at the Union's borders by 2021.[1]

Concerns over carbon leakage are motivated by the observation that the carbon intensity gap between high income and low and middle income countries has increased by 19% since 1990 (World Bank, World Development Indicators).[2] Yet, while the relocation of dirty production from high income to low income countries may well have contributed to the clean-up of production in developed countries, a competing explanation is that environmental policies triggered energy-saving technological change and associated reductions in the emission intensity of output (Levinson, 2009; Shapiro and Walker, 2017).[3] Empirical evidence using sector and country-level data lends strong support for this technological change explanation. Various decomposition methods indicate that the contribution of the so-called within-sector "technique" effect is significantly larger than that of between-sector "compositional" effect induced by international trade (e.g., Levinson, 2009; Cole and Elliott, 2013; Brunel, 2017; Shapiro and Walker, 2018).

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[1] At the time of writing, the proposal for a Carbon Border Adjustment Mechanism (CBAM) in 2021 is being discussed in the European Commission's Inception Impact Assessment (European Commission, 2020).

[2] The CO2 emissions per 2017 PPP $ of GDP decreased by 34% in high income countries and by 20% in low and middle income countries between 1990 and 2014. As a result, the carbon intensity gap increased from 123 g CO2 per 2017 PPP $ of GDP in 1990 to 146 g CO2 per 2017 PPP $ of GDP in 2014.

[3] In addition, international trade may magnify efficiency gains by increasing both income in developing countries (and thus demand for environmental policies; Copeland and Taylor, 1994; Antweiler et al., 2001) and competition (and thus innovation; Aghion et al., 2018). This could explain why the carbon intensity of production has also exhibited a marked downward trend in developing countries since 1990.

However, this result has been challenged by two pioneering works examining the impact of trade liberalization on emissions at the firm level (Li and Zhou, 2017; Cherniwchan, 2017). These studies reveal that the technique effect conflates true technological improvements with the offshoring of dirty tasks[4] within narrowly defined production lines. While these new findings are thought-provoking, firm-level evidence on pollution offshoring is still scant, confined to the US and local pollutants.[5] Moreover, due to data limitations on firm-level exposure to both import competition and domestic environmental policies, a comprehensive understanding of the underlined mechanisms remains so far limited.

Our paper provides new evidence to this debate by examining a global pollutant, CO_2, and a different country, France, over a longer time period of almost two decades, 1997-2014. To the best of our knowledge, we are the first to combine information on emissions, imports, imported emissions and environmental policy stringency, all at the firm-level. The unique features of our data allow making substantial steps forward in understanding how companies' environmental performance responds to both trade liberalizations and changes in environmental policy stringency.

One of the main contribution of our paper is to build a novel firm-level measure of imported emissions and decomposing its evolution into a technique (of the foreign countries), a composition, an intensive and an extensive (entry and exit) scale effect. We obtain our measure of imported emissions by weighting firm-level imports using data on the carbon intensity (direct and indirect) of each sector-country pair obtained from the combination of International Energy Agency (IEA) and the World Input-Output Database (WIOD) data. An advantage of our firm-level measure of imported emissions is that it can be easily extended to other firm-level datasets as it relies on publicly available data. Weighting imports by foreign emission intensity allow us to capture the environmentally-related motive of industrial relocation towards emerging economies and to go beyond Li and Zhou (2017) and Cherniwchan (2017), who focus on import volume from less developed countries, assuming that they have less stringent regulations than the US (e.g., Ederington et al., 2005),. By contrast, we directly measure actual differences in carbon intensity between sourcing countries. The idea is that companies already importing polluting goods from abroad may respond to an increase in

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[4] In this paper, we use carbon, dirty or brown tasks offshoring interchangeably to refer to the relocation of dirty segments of production abroad.

[5] A distinct exception is the paper of Cole et al. (2017) for Japan and CO2 emissions. However, they focus on extensive margin shift by examining the impact of a discrete choice of outsourcing on CO2 emission intensity.

environmental policy stringency through a further offshoring of dirty tasks that is not equally distributed across sourcing countries.

The subsequent step consists in correlating imported emissions with firm's domestic emissions and emission intensity, which are obtained from confidential data on the energy use and expenditures of French manufacturing establishments. To inspect the mechanisms behind the expected negative correlation between imported emissions and emission intensity, we perform two types of econometric analyses. First, similar to Li and Zhou (2017) and Cherniwchan (2017), we isolate the exogenous component of import competition shocks using a shift-share instrumental variable strategy (Bartik, 1991; Autor et al., 2013; Hummels et al., 2014). The idea of this instrumental variable strategy is to isolate the part of trade shocks that is supply-driven, i.e. driven by policy reforms occurring elsewhere than in France. In doing so, our preferred instrument reweighs global supply shocks outside France and its EU neighbouring countries ("the shift") using the pre-sample product mix of the firm multiplied by a proxy of the emission intensity of the product ("the share"). An advantage of our measurement framework is that we can compare the effect on emissions of total imports—as in Li and Zhou, 2017 and Cherniwchan (2017)–with that of imported emissions, by giving more weight to polluting products.

A second and novel contribution of this paper is to jointly examine the impacts of environmental policies and imported emissions on emissions intensity. Following previous research (Aldy and Pizer, 2015; Marin and Vona, 2017; Sato et al., 2019; Dussaux, 2020), we use the firm-level average unit energy cost as a proxy of environmental policy stringency. We address the endogeneity of firm-level energy cost by means of a similar and widely used shift-share instrument (see section 4.4). The introduction of a firm-level measure of policy is not only critical to assess energy price impacts on imported emissions, and thus the pollution haven hypothesis from a new angle, but also to test the relative incidence of the two main drivers of emission intensity improvements. Conditional on the impact of imported emissions, we interpret the direct effect of energy prices on emission intensity as a proxy of technology-inducement, thus revealing the relative importance of the trade and technology drivers (see Shapiro and Walker, 2017 for a similar argument).

Our analysis provides the following set of results. First, we document a significant increase of the carbon emissions embedded in imports of French manufacturing companies over the period 1997-2014. A change in the composition of imports, namely a shift towards more carbon-intensive products and countries, explains the bulk of this increase together with the entry of new firms into the import market.

Second, we find that a substantial impact of carbon offshoring on emission efficiency: a 10% increase in imported emissions leads to a decrease in emission intensity (emissions over turnover) of approximately 4%. Importantly, we find that import values and imported emissions have a similar effect on firms' emission intensity. Therefore, the carbon offshoring effect appears to be primarily the by-product of offshoring driven by other motives rather than the consequence of a pollution haven effect. Moreover, such effect partly captures efficiency improvement related to exporting rather than to the offshoring of dirty tasks. Overall, we cannot ascribe the carbon offshoring effect to firms' opportunistic behaviours to escape stringent environmental policies.

Third, we do not find compelling evidence of an impact of carbon offshoring on total emissions at the firm level. This result suggest that offshored emissions are compensated by an increase in production scale since emission efficiency improves in companies offshoring emissions abroad.

Fourth, the effect of carbon offshoring does not overlap with (and is not driven by) the effect of energy prices on emissions. Holding everything else equal, firms paying higher energy prices do not offshore emissions more than otherwise similar firms. In turn, the elasticity of energy price on emission intensity improvements is almost twice as large than that of carbon offshoring. However, since the historical growth rate of energy prices is twice as large that of imported emissions, the average emission intensity would have been 167% higher if energy price did not change between 2000 and 2014 and 43% higher if carbon offshoring did not change between 2000 and 2014.

This paper contributes to the empirical literature on the impact of environmental policies on carbon leakage. Exploiting trade flows at the sector- country level, Aichele and Felbermayr (2015) document a substantial increase in the carbon content of trade between countries committed and uncommitted to the Kyoto protocol (+8%). Aldy and Pizer (2018) focus on energy prices in the US manufacturing sector and find a modest negative effect on trade flows, which is concentrated in energy-intensive industries. Saussay and Sato (2018) show that differences in energy prices affect FDI location decisions of multinational companies, but the effect is rather small, while Cole et al. (2014) find a larger effect of a self-reported measure of environmental regulation on the probability of outsourcing of Japanese companies. Our paper also relates to Ben-David et al. (2018) who find that public companies facing more stringent environmental regulation in their headquarter country reduce their domestic emissions while increasing their foreign emissions. Their paper differs from ours in several dimensions. First, they focus on 4,500 large public companies based in 48 countries while our sample is composed of 5,000 small, medium, and large French manufacturing firms. Second, they use self-reported carbon emissions data whereas we directly measure carbon emissions imbedded in the firms' import. Third, we address the endogeneity of environmental regulation using an instrumental variable strategy.

In contrast with these papers which suggest the existence of carbon leakage, two recent studies find no effect of the EU-ETS on the carbon content of trade flows (Naegele and Zaklan, 2019) and on carbon leakage within multinational companies having a foreign affiliate outside Europe (Dechezleprêtre et al., 2019).[6] A plausible explanation for this discrepancy is the well-known lack of stringency of the EU-ETS, which justifies the focus on energy prices here. We add to this literature by assessing the effect of energy prices on imported emissions, thus looking at the intensive margin shift of polluting activities within a company, using a larger sample of firms and a longer time span.

The reminder of the paper is organized as follows. Section 3 briefly outlines the conceptual framework. Section 3 presents the data, measurement and descriptive statistics. Section 4 presents the empirical strategy used to identify both price and import effects. Section 5 contains the main results of the paper. Section 6 concludes.

2. Conceptual Framework

Our empirical framework is motivated by a theoretical extension of the pollution haven hypothesis, known as pollution offshoring, which applies the concept of comparative advantages to product-level value chains (for a review, see Cole et al., 2017).

Cherniwchan et al. (2017) formally define pollution offshoring using the task-based approach to production. In this approach, output is produced by a set of related tasks, while production factors (i.e. energy, labour, etc.) compete to perform each task. A dirty task is a task where polluting inputs have a comparative advantage. Just like every task, a dirty task can be done within a company or be outsourced to other companies, either abroad or at home, depending on the relative cost of dirty inputs. Since the cost of dirty inputs is also related to the stringency of environmental policies, which are country-specific, offshoring dirty tasks abroad may occur to escape an increase in environmental policy stringency at home.

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[6] Two related papers using firm-level data find that the EU-ETS increased outward FDI in Italy (Borghesi et al., forthcoming) and Germany (Koch and Basse Mama, 2019). However, they do not directly focus on the pollution leakage effect of the EU-ETS.

Overall, the task approach highlights two channels through which a unilateral increase in environmental policy stringency can affect firms' emission intensity: i) by relocating dirty tasks to pollution havens; ii) by reducing or eliminating the use of dirty inputs required to perform a single task, i.e. the "pure technique effect". A key contribution of our paper is to empirically assess the importance of these two margins at the firm level.

Importantly, as highlighted by Antweiler et al. (2001), a dirty task can be relocated abroad for other reasons than environmental policies. In particular, dirty tasks may complement a task in which cheaper unskilled labour or physical capital provides a comparative advantage.[7] Since labour and capital costs are larger than energy costs by an order of magnitude for the typical industrial sector, offshoring of dirty tasks may occurs as a by-product of industrial relocation driven by differences in the costs of other production factors. In section 5, we extend our empirical framework to discriminate between pollution offshoring driven by environmental policy stringency and pollution offshoring driven by other factors.

Finally, the carbon offshoring effect may conflate a technology inducement effect. A solid theoretical and empirical literature shows that accessing foreign markets boosts technological change and firm's productivity (e.g., Melitz, 2003; Bustos, 2011; Aghion et al., 2018). Several recent papers find that this happens also for energy and emission efficiency (e.g. Forslid et al., 2017; Barrows and Ollivier, 2018a and 2018b; and Gutiérrez and Teshima, 2018). Exporting and multinational firms have generally lower emission intensity than similar firms, and thus may respond differently to policy shocks.[8] Because importing firms are generally also exporting and our data are no exception on this, the export margin of adjustment to international competition can contaminate the interpretation of our results as revealing the avoidance of environmental regulation in France rather than the effect of trade on innovation. In section 5.3, we explore the possibility that the effect of carbon offshoring is driven by a positive relationship between exporting and efficiency gains, although, as will be discussed there, a clear identification of the two margins remains problematic.

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[7] The task model of comparative advantage simplifies the analysis by assuming that each task is produced using one input only (e.g., Grossman and Rossi-Hansberg, 2008; Acemoglu and Autor, 2011). Complementarity and substitutability among tasks (and thus production factors) take place at the level of task production function.

[8] On the relationship between export status and emission/energy intensity or investment in abatement technologies, see Batrakova and Davies (2012), Rodrigue and Soumonni (2014), Girma and Hanley (2015), Forslid et al. (2017), Jinji and Sakamoto (2015), Holladay (2016), Cui et al. (2016), Barrows and Ollivier (2018a,b) and Gutiérrez and Teshima (2018). Fewer papers studied the environmental performance of multinationals compared to domestic firms, e.g. Eskeland and Harrison (2003), Cole et al. (2008), and Brucal et al. (2018).

3. Data, Measures and Descriptive Statistics

This project relies on the combination of several data sources. As in related works on the impacts of environmental policies at the firm-level (e.g. Martin et al., 2014), we focus on the manufacturing sector, which is both polluting and the most involved in international trade. Table 1 summarizes the sources and use of the data in the paper. Further details about the data are given in the following sub-sections.

[Table 1 about here]

3.1. Data and Measures

Domestic Emissions and Energy Prices. Domestic emissions and energy prices are obtained from the Enquête Annuelle sur la Consommation d'Énergie dans l'Industrie (EACEI) conducted by the French statistical office (INSEE). EACEI collects data on consumption of electricity, natural gas, coal, oil, and other fuels (12 energy sources in total) for manufacturing establishments. As in similar plant-level surveys, sampling probabilities depend on size. All plants having at least 250 employees are included in EACEI, while plants with more than 20 employees are sampled through a two-level stratification procedure based on employment class and location. The response rate is very high: for example, 90% of the plants surveyed responded to the 2014 wave. To compute plant-level CO_2 emissions from fuel combustion, we follow the common practice of multiplying CO_2 emission factors from the French Environment and Energy Management Agency (Ademe) for each different fuel source available in EACEI (Marin and Vona, 2017; Forslid et al., 2018; Barrows and Ollivier, 2018; Dussaux, 2020).

The EACEI survey allows to retrieve the average unit energy cost, which is equals to the ratio between energy expenditure and energy consumption in toe. Following previous works (e.g., Davis et al., 2014; Aldy and Pizer, 2015), we refer to the average unit energy cost as energy price and we use it as a proxy of environmental policy stringency.

The main dependent variables used in this paper are CO2 emissions (in tons) and emissions intensity. The latter is computed as emissions per unit of output, which has been deflated using sectoral deflators provided by the INSEE. We also checked the robustness of our results to the use of Value Added to rescale emissions, as it is not clear which measure is theoretically better.

Imports and Imported Emissions. We use data on imports by product and destination from custom offices (so-called Données Douanes). Import data are available at the firm level, so we aggregate the plant-level EACEI data at the firm level to analyze the relationship between trade liberalization and emissions at the level of aggregation where trade shocks occur. Previous studies perform plant-level regressions, but they measure imports at a more aggregated level, i.e. either sector (Cherniwchan, 2017) or firm (Li and Zhou, 2017). An advantage of our study is that we observe both the dependent and the main variable of interest at the same level of aggregation, thus reducing possible measurement error.

Practically, to aggregate EACEI data at the company level, we need to retain only those companies whose establishments are fully (or almost fully) covered in EACEI. To do this, we compute the proportion of each firm's employees working at all of the firm's establishments observed in the survey, using the Déclaration annuelle des données sociales (DADS), a database containing information on employment-related variables for the universe of French establishments. As a threshold for inclusion in our baseline estimation sample, we keep firms with a share of employment covered in EACEI of 90% or more and impute carbon emission proportionally.[9]

To calculate imported carbon emissions, we combine confidential custom office data with data on foreign emission intensity at the country-sector level computed using emissions data from the International Energy Agency (IEA) and real output data from the World Input Output Database (WIOD) socio-economic accounts released in 2013 and 2016 (see Table 1). We use the 2018 edition of the IEA *CO_2 emissions from fuel combustion* database to compute emission intensities by country, sector and year. The IEA database covers annual data for 143 countries, 12 industrial sectors for more than 40 years (1971-2016).[10] Emissions are calculated using the IEA energy database and emission factors similar to those used for domestic emissions. The IEA energy database provides emissions for each fuel separately as well as for all fuels altogether. The IEA emission data have two key advantages compared to the emission data of the WIOD environmental accounts: 1) a greater coverage in terms of countries and years as WIOD emissions are available from 1995 to 2009 and only for a limited number of countries; 2) a criterion of measuring CO2 emissions that is consistent with that used in the EACEI

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[9] For example, if only 92% of a firm's employment is covered in EACEI, we multiply observed emissions by 1/0.92.

[10] Chemical and petrochemical, Food and tobacco, Iron and steel, Machinery, Mining and quarrying, Non-ferrous metals, Non-metallic minerals, Non-specified industry, Paper, pulp and printing, Textile and leather, Transport equipment, Wood and wood products.

dataset. Indeed, IEA data consider only CO_2 emissions from fuel combustion, which represent 95% of total CO_2 emissions at the world level.[11]

The imported emissions of firm *i* are computed as follows:

$$ImpE_{it} = \sum_k \sum_j M_{ijt,k\in s}\, EI_{jt,k\in s} \qquad (1)$$

$EI_{jt,k\in s}$ is the total (direct plus indirect) emissions intensity (i.e. tons of CO_2 per unit of real output) of product k of sector s in sourcing country j, while $M_{ijt,k\in s}$ is the imported quantity of firm *i* of products k of sector s from sourcing country j. Import values are deflated using the methodology proposed by Gaulier et al. (2008). Appendix A contains further details on the methodology used to deflate output and imports, the crosswalk between IEA and WIOD sectoral classifications and the management of missing data and outliers on foreign countries' emissions.

Two issues are worth discussing at this point. First, direct carbon emissions capture only part of the emissions generated to produce a unit of output inside the foreign country. Therefore, to compute EI_{jst}, we sum emissions directly generated by sector s in country j and emissions indirectly generated through the use of intermediate inputs from upstream sectors in country j. We use the World Input Output Tables (WIOD) to allocate emissions to countries and production stage.[12]

Second, since detailed data on emission intensity at the product-country-year level are not available, our working assumption in equation (1) is to assign a uniform level of emissions per unit of output to all products *k* imported from the same sector-destination pair in year *t*. We are aware that this is a limitation of our study in light of what found in the only study with product-level emission factors (Barrows and Ollivier, 2018). We relax this assumption using an alternative measure of emission intensity, which also exploits time- and country-invariant

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[11] Calculations based on the World Development Indicators database. The ratio between CO2 emissions from gaseous fuel consumption, liquid fuel consumption, solid fuel consumption and total CO2 emissions equals 95% for the 1994-2014 period.

[12] More specifically, we compute total emission intensity in foreign country as follows:

$$EI_{jst} = \frac{E_{jst}}{Y_{jst}} = \frac{1}{Y_{jst}}\left(E^D_{jst} + E^I_{jst}\right),$$

where E_{jst} is the total CO2 emissions from fuel combustion of sector s in country j for year t, Y_{jst} is total real output of sector *s* in country *j* for year *t*, E^D_{jst} are direct emissions and E^I_{jst} are indirect emissions, computed as $E^I_{jst} = \sum_l Y_{jslt} E^D_{jlt}$. Y_{jslt} is the amount of output of sector *j* used as input in sector *s* in the same country (from Input-Output tables of WIOD). Therefore, indirect emissions are only those generated within the same country.

carbon content of products derived from life-cycle assessments (see Sato, 2014). Because results barely change when using this measure, further details on how we build it are relegated to Appendix A. We decided not to use this corrected measure as the quality of product-level data on carbon content are time- and country-invariant and their quality is not certified by international organizations.

A final remark is warranted before turning to the empirical analysis of the relationship between carbon offshoring and domestic emissions. We have substantial sample selection issues for three reasons (see also Marin and Vona, 2017). First, the information on emissions is obtained from the EACEI survey on approximately 10,000 establishments per year. Second, only a subset of firms import for at least three years, which, as explained in next section, is the minimum required to compute the firm fixed effect and the instrument. Third, imports are available at the firm level, thus we also aggregate emissions at this level. In doing so, we lose representativeness because we retain firms for which we can observe at least 90% of establishments. For instance, firms in our estimation sample cover a modest share of imported emissions (approximately 20%) as many importing companies are not surveyed in EACEI.

3.2. Descriptive Evidence

We motivate our research with two pieces of descriptive evidence. First, Table 2 illustrates a well-known fact: emission intensity in developed countries, in our case France, is significantly lower than emission intensity in emerging and developing economies (we choose China as an example). The emission efficiency gap is significantly larger for indirect emissions, primarily due to the large gap between coal and nuclear power. This suggests an obvious fact and a less obvious one. On the one hand, the massive relocation of industrial activities towards China and other emerging economies likely contributed to explaining the exponential increase in global emissions in last two decades. On the other hand, the gap is large in both energy and non-energy intensive sectors such as textile. This suggests that differences in environmental regulation, which mostly affects energy-intensive industries, may not be the main factor behind the emission intensity gap.

[Table 2 about here]

The central idea behind the theory of task offshoring is that compositional effects occur both within and between firms. In the specific case of pollution offshoring, this implies that compositional shifts are the main force driving the increase in imported emissions. As a first step to understand whether foreign emissions have contributed to the decrease in domestic ones, we decompose the trend in imported emissions into its main components: scale, composition, entry and exit, and technique (see Appendix B for details). In Figure 1, the blue line with circle corresponds to the actual evolution of imported emissions that are by definition identical to the sum of the different components of the decomposition. The bottom line of the decomposition is that changes in the product mix have been the main drivers of the 34% increase in imported emissions that we observe in the French manufacturing sector. In the absence of the other effects, changes in the product mix would have increased the carbon content of imports by 69% (see Table 1B). Interestingly, technical improvements in emerging economies contributed to mitigate the increase in the carbon content of trade for French manufacturing. This result is consistent with those of papers showing that FDI decreases emission intensity in developing countries (e.g., Brucal et al. 2018), but make the product mix in those countries dirtier (Barrows and Ollivier, 2018). Over the years, more and more firms started importing.[13] This is consistent with decreasing trade costs, the extension of the European Single Market, and the numerous trade agreements introduced between European member states and other countries during that period. However, the intensive scale effect is negative. In other words, the emissions of firms already in the market due to change in import volume decreased over time. This is because the number of French manufacturing firms got smaller over time (Insee, 2018).[14] The fall in the intensive scale effect in between 2008 and 2009 is also consistent with 14% fall in manufacturing output during the global financial crisis (see Figure 1).

[Figure 1 about here]

Note that the results of the decomposition do not change if we use the alternative measure of imported emissions, which corrects for time-invariant differences in the carbon content of products (Table 2B). Both our favourite measure and the alternative at the product-level are imperfect, but for different reasons. However, we are reassured by fact that we find similar results using either.

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[13] More exactly, there have been more firms that started importing than firms that stopped importing.

[14] Notably, firms having more than 1,000 employees, more likely to import, decreased their size measured by their average number of employees by 9% between 2006 and 2015 suggesting that on average their production and import volume decreased as well over the same period.

To compare the estimation sample with the population of French manufacturing companies, we report in the Appendix the evolution of the dependent variable for the whole population of French manufacturing companies (Figure 1B, using IEA-WIOD data) and our estimation sample (Figure 2B, using EACEI and FARE-FICUS data). The main takeaway is that, except for the anomaly of year 2001 in our estimation sample, CO_2 emissions, emission intensity and output display a similar qualitative pattern in the whole population and in our main estimations sample. In addition, the magnitude of the changes is similar, although turnover grows less in our sample than in the whole population. We observe an increasing trend in imported emissions both in the entire population and in our estimation sample, which is mostly driven by emissions from non-OECD countries (Figure 3B).

Table 3B in the Appendix contains detailed descriptive statistics on the evolution of the main variables of interest for our main estimation sample of "always importers" (panel A) and the 281 companies always present in our estimation sample (panel B).[15] By using firms always importing we can precisely identify the intensive margin shift triggered by trade liberalization. Including also occasional importers would also reveal the direction of the extensive margin shifts. However, we cannot satisfactorily address the issue of self-selection into trade because it is extremely difficult to find an instrument for trade participation (see also Carluccio et al., 2015 on this issue). In what follows, our empirical strategy is primarily designed to identify the within-firm intensive margin shift. This within-firm intensive margin shift captures the carbon offshoring linked to the import of intermediate rather than final goods. If the production of polluting companies is entirely relocated abroad in response to differences in environmental policy stringency, then it is worth noting that our estimate will represent a lower bound of carbon offshoring driven by a pollution haven motive since it does not capture that extensive margin shift.

4. Empirical Strategy

This section presents the empirical strategy to estimate the carbon offshoring effect. We first focus on the identification of this effect. Second, we turn to the second main contribution of this paper: assessing the relative importance of offshoring and policy-induced effect in reducing CO_2 emission intensity.

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[15] As there are clear outliers in emission data, we drop the top and the bottom 1% of observations in all analyses of this paper.

4.1. Estimation Equation

Our starting point is the following reduced-form specification:

$$ln(e_{it}) = \alpha \cdot ln(ImpE_{it}) + \tau_{kt} + \theta_{rt} + d_{i,t=0} \times \varphi_t + \mu_i + \varepsilon_{it}. \qquad (2)$$

At this stage of the discussion, the main coefficient of interest α capture the contemporaneous association between emission intensity e_{it} (or emissions E_{it}) and imported emissions $ImpE_{it}$. The log-log specification corrects for the skewed distributions of both imports and emissions, while allowing a straightforward interpretation of α as an elasticity of domestic to imported emissions.[16]

We include firm fixed effects μ_i to control for time-invariant unobservable characteristics that are correlated with both imported and domestic emissions. Similarly, region-by-years θ_{rt} and sector-by-year dummies τ_{kt} absorb demand and supply shocks in the local labour market (NUTS2 regions) or sector of activity (2-digit NACE rev.2), respectively.

Controlling for firm size is important because size is a key and well-known determinant of both productivity improvements and firms' engagement in import and export in Melitz-type models (e.g., Melitz, 2003; Bustos, 2011). However, the direct inclusion of firm's turnover among the covariates is problematic because turnover is endogenous and thus a bad control, leading to biased estimates of α (Angrist and Pischke, 2008). To break the dynamic association between size, productivity and imports while comparing firms of similar size, our favourite specification allows for differential trends in emissions depending on initial size dummies $d_{i,t=0}$, measured as the deciles of the initial distribution of turnover. Given the long panel used in our study, initial size may fail to account for time-varying size effects. Consequently, we cannot exclude that the relationship between emissions and imported emissions is spurious, reflecting the simultaneous correlation of these two variables with size. By contrast, the residual influence of size is mitigated when we estimate the association between emission intensity and imported emissions. Therefore, although we are interested in the effect of import competition on both emissions and emission intensity, the remainder of the paper primarily focuses on the latter.

The main source of variation left to identify carbon offshoring is the within-firm one, depurated from any shocks common to firms in the same sector, region and size class. This is similar to the approach followed in related papers of Li and Zhou (2017) and Cherniwchan (2017), which

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[16] To deal with the skewness of the distribution of CO_2 emissions, our main results are obtained by dropping the top and the bottom 1% of observations. Results are consistent when keeping those outliers.

focus on the within- rather than the between-firm variation as a first step to isolate a causal effect.

4.2. Endogeneity Issues

Ideally, we would like to use our estimates of α to answer policy relevant questions such as the effect of a tariff reduction for dirty products on domestic carbon intensity. Estimating α through equation 2 is not enough to answer these questions for well-known endogeneity concerns that are mitigated, but not solved, by the inclusion of firm fixed effects. Time-varying unobservables such as demand and supply shocks may affect both emission intensity and imported emissions, leading to inconsistent estimates of the carbon offshoring effect. Moreover, imported emissions are measured with error because we do not have a precise proxy of carbon content at the product level. Such measurement error generates an attenuation bias in our OLS estimates. Finally, reverse causality can be an issue as long as forward looking managers adjust their product mix (and so the imported product mix) to reduce current and future emissions in response to anticipated regulatory changes.

The direction of the estimation bias is not straightforward *a priori*. Unobserved shocks to the French product market are positively correlated with imports, but their association with emission intensity is unclear. Domestic supply shocks relevant for emission intensity and imports are primarily related to the adoption of energy-saving technologies. Theoretically, adopting energy-saving technologies is the main alternative strategy to the offshoring of dirty tasks. Therefore, firms that adopt such technologies should have both lower emission intensity and lower imported emissions. If α is negative, we expect a bias toward zero which is amplified by the standard attenuation bias due to measurement error in imported emissions. Overall, we expect the OLS estimate of α to go against the existence of the carbon offshoring effect.

Following the seminal contributions of Autor et al. (2013) and Hummels et al. (2014), we use global supply shocks directed to other countries but France and its neighbouring countries to mitigate the bias in the estimate of carbon offshoring. This instrument captures the potential exposure to such shocks and has a typical shift-share structure:

$$IV\_ImpE_{it} = \sum_p \bar{e}_{p,t<t_0} \bar{s}_{ip,t<t_0} \times WS_{pt}, \qquad (3)$$

where WS_{pt} is the shift component, namely world exports of product p in year t. To isolate supply shocks outside core EU countries, we consider world export WS_{pt} directed to all countries but France and countries' bordering France (i.e., Germany, Spain, Italy, UK, and Belgium). $\bar{s}_{ip,t<t_0}$ is the main share component, namely the average pre-sample share of

product p imported by firm i in the three periods before the first period t_0 in which the firm is observed in the sample. In our favourite specification, the shares $\bar{s}_{ip,t<t_0}$ are reweighted by pre-sample emission intensity $\bar{e}_{p,t<t_0}$ in all countries except France to emphasize the environmentally related motive of industry relocation. Indeed, the instrument and thus the exposure to supply shocks takes a higher value if p is more polluting. Using pre-sample share mitigates the reverse causality bias discussed above, but implies that we reduce the time span used to estimate the carbon offshoring effect to 2000-2014.[17]

4.3. Validation of the instrumental variable strategy

Our instrument identifies the carbon offshoring effect provided that: (i) it is a good predictor of firm's imported emissions; and (ii) it excludes the components of import shocks that are dependent on shocks in the French economy, as well as on forward-looking behaviour of managers. Table 3 in the appendix illustrates that the instrument is a good predictor of imported emissions (and a classical instrument not weighted by emission intensity is a good predictor of imports in value) with an F-test passing the usual threshold of 10, with one exception that has to do with the issue of firm size and will be discussed in section 5.1. As would be expected, imported emissions grow faster in firms with a dirtier initial mix of imports (i.e. the share component of the instrument). The strength of the instrument is consistent with two well-known facts of the French Custom data; that (i) the set of imported product is very stable over time and (ii) there is little overlapping of product-specific shocks across firms (Carluccio et al., 2015).

On the second assumption, there are two main concerns that can invalidate our identification strategy. First and foremost, our instrument may be correlated with pre-existing trends in emissions. Finding a positive correlation between our instrument and pre-sample emission trends may indicate that the carbon offshoring effect captures past emission trends. Second, forward-looking managers can adjust their import mix in response to future shocks, in particular policy shocks such as the EU Emission Trading Scheme. Using pre-sample shares in building our instrument mitigates but not fully solves this concern.

To lend support to our identification strategy, we make full use of our long panel by explicitly testing the correlation between pre-trends in emissions (or emission intensity) and the instrument. We capture pre-trend in dependent variables with two proxy: (i) the average of the

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[17] In our set-up, pre-sample shares are computed as the average between $t_0 - 1$, $t_0 - 2$ and $t_0 - 3$, where t_0 is the first year in which we observe the firm. This implies that a firm should be observed for at least 3 years to be included in our main estimation sample.

change in the logarithm of emissions over the period 1995-1999 and (ii) the average of the logarithm of emissions over the same period. We regress the instrument on the standard controls of equation (2) and the interactions between the pre-trend variables and a time trend. We focus on the subsample of firms observed before 2000 for this exercise also to mitigate the second concern discussed above. Indeed, it is extremely unlikely that the import mix of such companies before 2000 incorporated responses to future policy shocks.

Table 4 shows that past trends in emission intensity are uncorrelated with the instrument (col. 1-2), while past changes in emissions display a positive and weakly significant association (p-value = 0.1) with the instrument (col. 3-4). Although these results reassure us on the validity of our identification strategy, we exclude the possibility that pre-trends drive our results by adding them to the set of covariates of equation 2. This key robustness check also tests whether results are different for the sample of firms that are less likely to incorporate future regulatory shocks in their decisions.[18]

Finally, as suggested by Jaeger et al. (2018), the interpretation α is not straightforward as it may conflate past and present responses to trade shocks. For sake of interpretation, we explicitly account for the adjustment dynamics by adding lags of imported emissions to equation 2 and instrumenting each lag with the corresponding lagged instruments, built as in equation 3.

4.4. Role of Policies

We use energy prices as proxies of policies (Aldy and Pizer, 2015; Marin and Vona, 2017; Sato et al., 2019; Dussaux, 2020). Our measure of energy prices is the average cost of energy from the EACEI dataset. We include energy prices in equation 2, so we can compare the role of policy with that of carbon offshoring:

$$ln(e_{it}) = \alpha \cdot ln(ImpE_{it}) + \beta \cdot ln(p_{it}) + \tau_{kt} + \theta_{rt} + d_{i,t=0} \times \varphi_t + \mu_i + \varepsilon_{it}. \qquad (4)$$

Conditional on carbon offshoring, we interpret the impact of energy prices on emission intensity β as an induced innovation effect. Energy prices are typically endogenous due to the presence of omitted variables, such as managerial capabilities and unobservable demand and

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[18] Forward looking managers may adjust the current income product mix in response to expected changes in regulation, such as changes in the price of allowances in the EU Emission Trading Scheme. The pre-sample period of 1997-1999 for the companies in this restricted estimation sample are well before the beginning of the pilot phase of the EU-ETS and of all structural transformations that characterized the 2000s.

supply shocks. Marin and Vona (2017) show that quantity discounts are a typical source of endogeneity.

We follow a now standard approach in the literature and use a shift-share instrument also for energy prices (Lynn, 2008; Marin and Vona, 2017; Sato et al., 2019; Dussaux, 2020). The instrument is:

$$IV\_p_{it} = \sum_f w_{i,t=t_0}^f \ln\left(p_{kt}^f\right), \qquad (5)$$

where $w_{i,t=t_0}^f$ is the share of fuel f (i.e. electricity, gas, oil, etc.) in total energy use of firm i at the pre-sample year 0 and p_{kt}^f is the median price of fuel f for the 3-digit industry k in which firm i operates at year t. As for import, using pre-sample weights mitigate concerns related to reverse causality and simultaneity biases. The exclusion restriction is that the initial energy mix has an effect on emissions only through the exposure to exogenous price shocks. Like for the case of imported emissions, this restriction is difficult to test in practice.

Table 5 replicates for the instrument of energy prices the analysis on the influence of emission pre-trends done in Table 4. Consistent with results at establishment-level analysis (Marin and Vona, 2017) and firm-level analysis (Dussaux, 2020), past trends in both emissions and emission intensity are highly correlated with IV_p_{it}, thus raising concerns on the credibility of the energy price instrument. To mitigate possible concern on the bias of the IV estimates, in the main tables we always present an alternative specification where we control for pre-trends in emissions or emission intensity.

5. Estimation Results

This section is divided in four subsections. In section 5.1, we begin by presenting the effect of carbon offshoring on total emissions. We then move to our main results on emission intensity in section 5.2 and to two critical extensions in section 5.3. Finally, we examine the extent to which results on emission intensity are driven by changes in energy prices in section 5.4.

All results are obtained estimating variants of equations 2 and 4, in which we cluster standard errors at the company level. Importantly, we do not weight the estimates since, as we discussed above, our sample is not representative of the French population of manufacturing company.

5.1. Results on Emissions

Table 6 presents the carbon offshoring effect for total emissions. We find a positive and significant, although very small, association in the OLS specification (column 1). The effect remains positive, but becomes insignificant in our favorite IV specification (columns 2). The absence of a negative correlation between domestic and imported emissions is at odds with the descriptive evidence presented in Section 3. While on average there is a concomitant decline in domestic emissions and an increase in imported emissions, these do not seem to occur within the same company. Previous papers of Li and Zhou (2017) and Cherniwchan (2017) find a negative effect for local pollutants but their study does not include carbon emissions.[19]

A possible explanation for obtaining a different result is that we do not properly account for the scale effect by using time trends specific to the deciles of initial turnover. Since average turnover increased substantially in the period of our analysis, a scale effect may fully offset the substitution effect associated with the offshoring of domestic emissions abroad. To tackle this issue, we amend our main estimation equation (1) by directly including turnover instead of initial turnover dummies interacted with year dummies. Column 3 presents this extension. Although the negative sign and the magnitude of elasticity between domestic and imported emissions indicates the presence of carbon offshoring, the lack of statistical significance and the weakness of the instrument prevent us from drawing any solid conclusion (see also the first-stage results in Table 3). Column 4 shows that both the precision of the estimate (p-value = 0.110) and the predictive power of the instrument improves considerably when we consider a shorter time span 2000-2005. This is consistent with the structure of shift-share instruments, whereby the initial share is fixed before 2000 and thus loses predictive power the farther the year is from 2000.

In the Appendix, we show that explicitly controlling for pre-trends in emissions leads to similar results (Table 1C). However, both the precision of the estimates and the strength of the instruments increase in the subsample of firms present before 2000, which is used to capture the influence of pre-trends.

Overall, the firm-level analysis highlights an important methodological challenge in estimating the effect of trade liberalization on emissions. The result of Table 6 confirms that reduced-form strategies fail to control satisfactorily for size effects when the dependent variable is not rescaled, such as for the case total emissions. In light of this result, the reminder of the paper will focus on emission intensity which, by incorporating turnover into the dependent variable, captures the net effect of import competition that results from the combination of a scale and a substitution effect.

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[19] Cherniwchan (2017) focuses on particulate matter and sulphur dioxide while Li and Zhou (2017) focus on toxic emissions equal to the all-media release of designated toxic chemicals.

5.2. Results on Emission Intensity

Table 7 exposes the main results of the impact of carbon offshoring on emission intensity. The key finding is that carbon offshoring improves the domestic efficiency in the use of dirty inputs. In our baseline IV model (column 2), the elasticity is quite large (-0.49), but slightly declines to -0.39 if we control for pre-trends in the restricted sample of firms present before 2000 (columns 3). Column 4 shows that it is controlling for pre-trends and not considering firms present before 2000 that reduces the size of the elasticity. Using the conservative estimates of -0.39, domestic emission intensity would have been 33% higher if imported emissions remained at the level of the initial years (2000-2002).[20]

When we compare the OLS (column 1) and the IV (column 2) estimates for emissions and emission intensity, the bias towards zero of OLS estimates becomes evident in a specification where scale effects are incorporated in the dependent variable and the F of the excluded instruments in the first-stage is always well above the conventional threshold of 10. Following the discussion in section 4.2, we interpret this bias as the resultant of unobservable technological choices correlated with both emission intensity and offshoring. In response to external regulatory pressure, public opinion and stakeholders, managers can reduce the carbon content of production either by innovating or by relocating polluting tasks abroad. By construction, our two-stage IV strategy estimates an average effect for the compliers; that is: those who decide to offshore in response to a reduction in the implicit cost of dirty tasks' relocation. Non-compliers, instead, are insensitive to the new offshoring opportunity. Compliers are likely to be innovators and thus display low emissions intensity and low import of polluting goods, thus explaining the direction of the estimation bias. This LATE (local average treatment effect) interpretation of our instrument variable strategy is important to again emphasize the fact that we do not claim to capture a global or representative effect (Angrist and Imbens, 2003).

In Appendix C, we present a series of robustness checks that confirm the presence of a relatively large carbon offshoring effect. First, we use two different instruments that exploit different sources of variation to estimate the carbon offshoring effect: (i) as in Carluccio et al.

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[20] We use in-sample figures for the evolution of emission intensity and imported emissions for always importers that are reported in Table 3B, panel A. To obtained the historical variation in emission intensity explained by carbon offshoring for the sample of the always importers, we multiply the unweighted growth rate of imported emissions based on the difference between the moving average of the last three years (2012-2013-2014) and the moving average of three first years (2000-2001-2002). We take the moving averages before computing the growth rates to avoid the influence of outlier years (e.g. 2001) in our quantification. The growth rate of imported emissions is equal to 25.7% (Table 3B), that is multiplied by the estimated elasticity of -0.39 to obtain predicted change in domestic emissions intensity. Then, we divide this predicted change in emission intensity with the historical one in the same sample and also computed using the moving average of the first three and the last three years (-30.2%).

(2015), we use origin-destination variation in the initial shares and total global exports as a shift; (ii) we use a different and arguably less exogenous shift, namely world exports of all countries except France and countries bordering France towards the countries bordering France (i.e., Germany, Spain, Italy, UK, Belgium). Results in Table 2C shows that the less exogenous instrument gives very similar results (columns 1 and 2), while a weak instrument problem emerges when we exploit the full product-by-country variation available in our data (columns 3-4).[21]

Remarkably, our results are unchanged when adding controls for capital intensity and labour productivity (Table 3C), allowing for a different carbon offshoring effect in sectors that are energy-intensive (Table 4C), measuring emission intensity as emissions over value added rather than turnover (Table 5C), including only firms fully covered in EACEI (Table 6C), weighting the regression by average turnover (Table 7C) and considering the larger sample of companies importing for at least three years (Table 8C and Table 9C). As would be expected, we find that carbon offshoring is stronger in energy-intensive sectors and that firms that are more productive are also less emission intensive, while capital- and emission-intensity are positively correlated. The carbon offshoring elasticity is also larger when we include occasional importers, suggesting that the extensive margin shift adds to the intensive margin effect that we estimate in our main specification.

Finally, using the Jaeger et al. (2018) approach to distinguish long- and short-term effects, we find that the effects estimated without including lagged terms in imported emissions are similar to those estimated including them (Table10C). Note that long-term effects are slightly larger than short-term ones, implying that our favourite specification provides a conservative quantification of carbon offshoring.

5.3. Interpreting the Carbon Offshoring effect

We perform two critical extensions to understand the mechanisms behind the carbon offshoring effect.

In the first extension, we aim at understanding whether carbon offshoring is driven by the massive shift in production towards emerging economies that occurred over the same time span and would mechanically generate carbon offshoring. In doing so, we replace imported emissions with imports in the model of equation 2. Results, presented in Table 8, reveal that

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[21] Note that this instrument becomes stronger when we use imports rather than imported emissions as main variable of interest. However, the results are in line with those estimated in the next section and are available upon request by the authors.

the estimated elasticity of emission intensity to imports is of a similar size, if not larger, of that of imported emissions.[22] However, the quantified impact of imports on emission intensity is of similar size of imported emissions as imports increased by only 18% in our primary estimation sample. This finding provides a first indication that the carbon offshoring effect is unlikely to be primarily driven by a Pollution Haven effect. By contrast, the general increase in the propensity to import of French companies, which has been associated with differences in labor costs (e.g. Autor et al., 2003; Pierce and Schott, 2016), appears the factor behind the increase of imported emissions. As a further corroboration of this interpretation, we find a positive but statistically insignificant impact of energy prices, instrumented as described in section 4.4, on imported emissions (Table 11C), which is consistent with existing results on the EU-ETS (Martin et al., 2014; Naegele and Zaklan, 2019). However, the effect becomes statistically significant (and large) on the share of imported on domestic emissions (column 5).

Overall, these two findings suggest that carbon offshoring is a by-product of industry relocation to non-OECD countries, that is to a large extent unrelated to environmental policy stringency. However, we cannot exclude that a Pollution Haven motive to relocate dirty tasks abroad plays also a minor role.

The second extension is connected with the literature on emission intensity and export (e.g. Forslid et al., 2017; Barrows and Ollivier, 2018a; and Gutiérrez and Teshima, 2018). As discussed in section 2, a voluminous literature suggests that trade liberalizations can improve significantly emission intensity of exporting firms through productivity-enhancement effect typical of Melitz-type models. In our estimation sample, most firms are both importers and exporters, thus we cannot exclude that such effect contaminates the carbon offshoring effect. Empirically, it is not easy to tackle this issue, as export status and intensity are also endogenous, thus it is difficult to find strong instruments for both imports and exports.[23] As a second best strategy, we allow for a differential effect of large exporters augmenting equation 2 with an interaction term between imported emission and a 'large exporter dummy', defined by an indicator function equal 1 for companies above the median export intensity over the entire sample period. Across the board (Table 9), large exporters reduce twice as much their emission intensity when their imported emissions increase. This result is consistent, although it is not

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[22] As for our main results on the impact of imported emissions on emissions, we find no effect of imports on emissions. Results are available upon request by the authors.

[23] By instrumenting both export (instrument built as in Carluccio et al., 2015) and imported emissions, the F of excluded instruments is below the cut-off level of 10. These results are available upon request.

causal evidence, with the well-known result of the literature on export and emission efficiency that engaging in trade itself leads to efficiency improvement.

An alternative way to address the extent to which broad differences in environmental policy stringency drives our results is to compare the carbon offshoring effect for OECD and non-OECD countries. Following Ederington et al. (2005), the idea here is that trade within 'rich' OECD countries is not primarily driven by asymmetric environmental regulations. Trade between OECD countries is usually associated to technological improvements than to cost savings. By contrast, trade in polluting industries between France and non-OECD countries is more likely to respond to a pollution haven effect and, in general, to cost-saving considerations. Table 10 shows that the carbon offshoring effect is present in trade with both groups of countries, but it is significantly stronger for OECD countries, contrary to what one would expect if importing is driven by differences in environmental regulation.[24] Note, however, that the volume of imported emissions increased significantly more for non-OECD (+61%) than for OECD countries (0.3%) over the sample period. Thus, the overall effect is clearly larger for non-OECD countries than for OECD countries.

This exercise further corroborates the two main conclusions of this section. First, a large share of emission intensity improvements due to trade are driven by other motives than pollution haven. Second, trade liberalizations have two effects on emission intensity: a carbon offshoring effect and a productivity-enhancing effect through export. This latter result deserves further scrutiny to assess more precisely the relative importance of these two margins through which trade affects emission intensity.

5.4. Energy Price vs. Carbon Offshoring Impacts

The final step of this paper is to go back to the fundamental question of the inducement effect of environmental policies and the relative role of carbon offshoring and technology in reducing the carbon footprint of French production (e.g. Levinson, 2009; Shapiro and Walker, 2018). The richness of the data used in this paper allows to tackle this issue looking at firm-level reactions. We add a proxy of environmental policies, energy prices, and properly instrument it as described in section 4.4. Conditional on carbon offshoring, the effect of energy prices on emission intensity can be interpreted as a technological inducement effect as in, e.g., Shapiro and Walker (2015). Table 11 presents the main results of this exercise. Since the instrument of

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[24] Imported emissions and the association instruments are modified to keep only imports from the relevant group of countries. Results remain the same if we split the OECD sample into rich-OECD and middle-income OECD and are available upon request. Ideally, we would include both imported emissions from OECD and from non-OECD in the same model but this leads to a multicollinearity issue.

energy prices is positively correlated with pre-trends in emission intensity, the main Table shows also the results controlling for pre-trend (columns 3-6). To assess the extent to which the inclusion of carbon offshoring alters the effects of energy prices, we present both the results of a specification without carbon offshoring (columns 1, 2, 4 and 5) and a specification with carbon offshoring (columns 3 and 6).

The first result is that carbon offshoring and price inducement effect are quite independent. The carbon offshoring effect slightly increases with respect to the effect estimated in Table 7, but it remains of the same order of magnitude. The policy inducement effect remains very similar if we include or not carbon offshoring (e.g., column 6 vs. column 5), which is consistent with the small and insignificant effect of energy prices on imported emissions that we have discussed in the previous section.[25] However, the policy inducement effect almost halves if we control for pre-trends in emissions intensity, in line with the diagnostics of Table 5 showing that pre-trends are an issue for the instrument used to estimate the effect of energy prices.

The second result is that the effect of environmental policies, as proxied by the effect of energy prices, is substantially larger than the effect of trade liberalization, as proxied by the carbon offshoring effect. The difference in the effect declines in the specification with pre-trends, but still the elasticity of energy prices is 0.926 versus an elasticity of carbon offshoring of 0.517. It is worth noting that, even in this case, we do not detect any change in the estimates of the carbon offshoring compared to the favourite specification using the same sample. When we use the estimates of column 6 to quantify the relative role played by energy prices and carbon offshoring, the difference in the two effects appear even larger as energy prices increases by more than 50% over the time period considered. We find that domestic emission intensity would have been 43% higher if imported emissions remained at the level of the initial years (2000-2002), while they would have been 167% higher if energy prices remained at the level of the initial years.

While these estimates should be taken with caution as tackling two causal problems in a reduced-form econometric model is always problematic, the important finding of this extension is that the carbon offshoring effect remains unchanged if we control or not for a proxy of environmental policy stringency. This result reinforces the main interpretation of our finding, that is: the within-firm carbon offshoring effect is not primarily explained by differences in environmental policy stringency.

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[25] The magnitude of the price effect is in line with what found by Marin and Vona (2017) on emissions, but slightly larger as our estimation sample is even more bias towards large companies involved in international trade.

6. Concluding remarks

In this paper, we use a unique dataset which combines information on carbon emissions, imports, imported emissions and environmental policy stringency, all at the firm level, on a panel of 5,000 firms operating in the French manufacturing sector, and show that imported carbon emissions cause a decrease in French firms' domestic emission intensity. Most importantly, we provide evidence suggesting that this carbon offshoring effect is not primarily due to differences in environmental regulations. Instead, our results suggest that trade liberalization and other factors such as differences in labour cost between countries are major determinants of carbon offshoring. Finally, we find that the stringency of domestic carbon pricing policies (as proxied by instrumented energy prices) has a much larger effect on firms' domestic emission intensity than on carbon offshoring.

The key policy implication of our results is that raising domestic carbon pricing does not lead to a substantial carbon leakage from stringent countries to countries with laxer policies within firms. Carbon leakage might still occur through competition on the final products market and firm exit, but the finding that it does not seem to happen within firms – at least, at the current level of carbon policy stringency gap across countries – is certainly reassuring as regards the effectiveness of unilateral carbon pricing policies.

The issue of border carbon adjustment is the subject of renewed interest and policy discussions in a context of increased divergence in climate policy ambition, where many countries and regions have decided to move towards carbon neutrality by 2050. Our results, combined with the complexity of designing BCAs that are both effective and compatible with the current multilateral system of trade rules and their potential to increase trade tensions, suggest that this policy instrument should be considered with caution as long as evidence for leakage remains weak. Further widening of policy stringency may however alter this conclusion.

Our paper has a number of limitations. First, although we cover a wide range of firms in terms of size and sector, our sample is overrepresented by large firms. This is an unavoidable feature of energy consumption surveys. Second, in our reduced-form specification, we do not explicitly model other factors affecting offshoring such as labour costs. Teasing out the impact of these various factors behind production cost differences on the location of carbon emissions is an interesting avenue for future research. Finally, we do not explore the role of the extensive margin of imports mainly because the empirical setting does not offer a suitable instrumental variable varying at the firm level. This is also left for future analyses.

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Figures and Tables

Table 1: Map of Data Sources

Confidential data	*Level*	*Years covered*	*Coverage*	*Main information as used in the paper*
EACEI	establishment	1994-2015	Survey on approx. 10k establishment per year	Domestic CO2 Emission, Energy prices
Custom data (données Douanes)	firm	1995-2014	Universe of importers and exporters	Import values and quantities
FARE-FICUS	firm	1995-2015	Universe of companies	Turnover and Value Added
DADS	establishment	1996-2015	Universe of establishments	Use employment weight to identify the companies with high employment coverage in EACEI (>90%)
Public Available	*Level*	*Years covered*	*Coverage*	*Main information as used in the paper*
WIOD (release 2013 and 2016)	sector-by-country	1995-2016	14 manufacturing sectors, 40 countries (OECD plus BRICS)	Turnover and input-output data to computed indirect emissions
IEA emission data	sector-by-country	1994-2017	14 manufacturing sectors, 281 countries	Emissions of foreign countries
Sato (2014)	product	time invariant	4-digit products, SITC classification	Carbon content of product, definition of dirty products

Notes: access to confidential data through the French Secure Data Access Center (CASD). Detailed administrative procedures for accessing the data are available in the website: https://www.casd.eu/en/. Sato (2014) data are available upon request by the author.

Table 2: Gap in emission intensity between China and France

Sector	Direct emission intensity			Indirect emissions		
	China	France	Ratio	China	France	Ratio
Mining and quarrying	147	172	0.9	1316	279	4.7
Food and tobacco	124	51	2.4	268	87	3.1
Textile and leather	69	24	2.9	229	48	4.8
Wood and wood products	56	17	3.3	254	46	5.5
Paper, pulp and printing	230	90	2.6	538	141	3.8
Chemical and petrochemical	328	45	7.3	910	77	11.8
Non-metallic minerals	1285	406	3.2	2066	506	4.1
Basic metals and fabricated metals	907	107	8.5	1701	162	10.5
Machinery	90	55	1.6	379	78	4.9
Transport equipment	20	13	1.5	179	42	4.3
Non-specified industry	116	5	23.2	316	20	15.8

Notes: authors' elaboration from IEA and WIOD data, year 2013.CO2 emissions in tons per millions of euro. Indirect emissions are computed considering only domestic emissions from other sectors.

Table 3: First-Stage Results

Specification	Endogenous variable	Coefficient of the instrument on the endogenous	standard error	F-statistics of excluded instruments
Emissions (Table 6)	Imp. Emissions	0.254	0.066	52.2
Emissions control for turnover (Table 7)	Imp. Emissions	0.058	0.061	3.1
Emissions Intensity (Table 8)	Imp. Emissions	0.254	0.066	52.2
Emissions Intensity (Table 9)	Imports	0.210	0.070	38.9

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. The instrument for imports is not weighted by emission intensity in foreign countries. Robust standard errors clustered at the firm level.

Table 4: Import Instrument and Pre-Trend in Emissions, 1995-1999

Dependent Variable: Instrument of imported emissions		
	Emission Intensity	Emissions
Time x pre-sample avg. emission intensity	0.0008	
(in log)	(0.0005)	
Time x pre-sample avg. changes in emission intensity	0.0025	
(in log)	(0.0015)	
Time x pre-sample avg. emissions (in log)		0.0007
		(0.0005)
Time x pre-sample avg. changes in emissions (in log)		0.0027*
		(0.0014)
Observations	23,530	24,247
Number of firms	2,762	2,857

Notes: Only firms always importing are included in the estimation sample. Sector-year, region-year and size-year fixed effects always included. These estimates are performed on firms for which we have at least two observations before 2000 to build pre-sample changes in emission (or emission intensity). Standard errors clustered at the firm level in parentheses. Statistical significance: *** p<0.01, ** p<0.05, * p<0.1

Table 5: Energy Price Instrument and Pre-Trend in Emissions, 1995-1999

Dependent Variable: Instrument of energy price		
	Emission Intensity	Emissions
Time x pre-sample avg. emission intensity (in log)	0.0030***	
	(0.0002)	
Time x pre-sample avg. changes in emission intensity (in log)	-0.0033***	
	(0.0006)	
Time x pre-sample avg. emissions (in log)		0.0025***
		(0.0002)
Time x pre-sample avg. changes in emissions (in log)		-0.0032***
		(0.0006)
Observations	20,612	21,278
Number of firms	2,437	2,524

Notes: Only firms always importing are included in the estimation sample. Sector-year, region-year and size-year fixed effects always included. These estimates are performed on firms for which we have at least two observations before 2000 to build pre-sample changes in emission (or emission intensity). Standard errors clustered at the firm level in parentheses. Statistical significance: *** p<0.01, ** p<0.05, * p<0.1

Table 6: Emissions and Imported Emissions

Dependent variable log(Emissions)				
	OLS	IV	IV turnover	IV turnover until 2005
Imported Emissions (in log)	0.0361*** (0.0057)	0.134 (0.129)	-0.574 (0.784)	-0.437 (0.271)
Turnover (in log)			1.110 (0.968)	0.740** (0.290)
Observations	35,537	35,537	35,540	12,500
Number of firms	4,962	4,962	4,962	3,239
F-test excluded instrument		52.18	3.088	15.52

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. In columns 3 and 4, we replace size class x year dummies with the log of turnover. In column 4, we run the model for the short time period 2000-2005. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Emission Intensity and Imported Emissions

Dep. Var. log(Emissions/ Turnover)				
	OLS	IV	IV, pre-trends	IV, pre-trend sample
Imported Emissions (in log)	-0.0615*** (0.0061)	-0.489*** (0.164)	-0.392*** (0.137)	-0.460*** (0.147)
Time x pre-sample avg. emission intensity (in log)			-0.0161*** (0.0016)	
Time x pre-sample avg. changes in emission intensity (in log)			-0.0141*** (0.0048)	
Observations	35,537	35,537	23,530	23,530
Number of firms	4,962	4,962	2,762	2,762
F-test excluded instrument		52.18	56.52	57.43

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Emission Intensity and Imports

Dep. Var. log(Emissions/ Turnover)				
	OLS	IV	IV, pre-trends	IV, pre-trend sample
Imported Emissions (in log)	-0.0935***	-0.840***	-0.564***	-0.742***
	(0.0074)	(0.295)	(0.216)	(0.246)
Time x pre-sample avg. emission intensity (in log)			-0.0153*** (0.0018)	
Time x pre-sample avg. changes in emission intensity (in log)			-0.0131** (0.0056)	
Observations	35,537	35,537	23,530	23,530
Number of firms	4962	4962	2762	2762
F-test excluded instrument		38.94	37.94	40.72

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 9: Emission Intensity, Imported Emissions and Exports

Dep. Var. log(Emissions/ Turnover)				
	OLS	IV	IV, pre-trends	IV, pre-trend sample
Imported Emissions (in log)	-0.0434***	-0.311	-0.268	-0.312
	(0.0121)	(0.196)	(0.173)	(0.190)
Large Export Dummy x Imported Emissions (in log)	-0.0241* (0.0138)	-0.240** (0.119)	-0.191 (0.142)	-0.229 (0.154)
Time x pre-sample avg. emission intensity (in log)			-0.0160*** (0.0016)	
Time x pre-sample avg. changes in emission intensity (in log)			-0.0148*** (0.0051)	
Observations	35,537	35,537	23,530	23,530
Number of firms	4962	4962	2762	2762
F-test excluded instrument		26.11	28.75	29.31

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The ‘large exporter dummy’ is defined by an indicator function equal 1 for companies above the median export intensity over the entire sample period. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 10: Emission Intensity and Imported Emissions, OECD vs. non-OECD countries

Dep. Var. log(Emissions/ Turnover)						
	OLS	IV	OLS	IV	IV pre-trend	IV pre-trend
Imported Emissions from non-OECD countries(in log)	-0.0135*** (0.0028)	-0.182* (0.110)			-0.171* (0.0988)	
Imported Emissions from OECD countries(in log)			-0.0617*** (0.0064)	-0.831*** (0.276)		-0.922** (0.413)
Time x pre-sample avg. emission intensity (in log)					-0.018*** (0.0019)	-0.012*** (0.0035)
Time x pre-sample avg. change in emission intensity (in log)					-0.0149** (0.0075)	-0.0078 (0.0074)
Observations	24,691	24,691	35,308	35,308	16,718	23,469
Number of firms	3836	3836	4935	4935	2231	2761
F-test excluded instrument		25.06		39.3	26.21	18.67

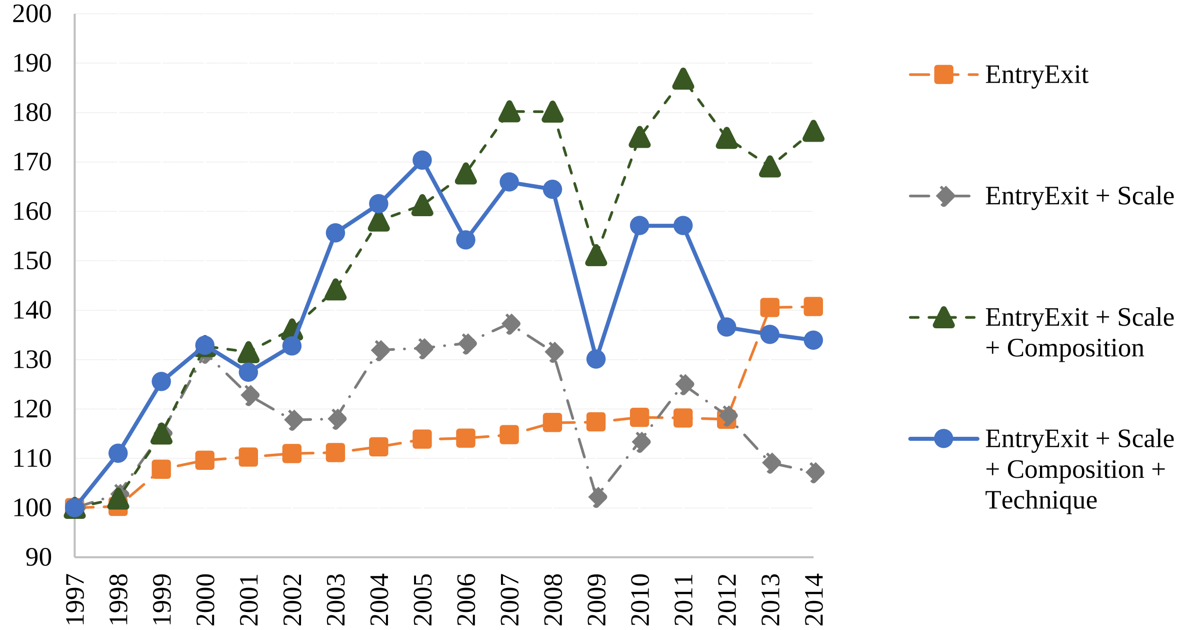
Notes: All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries. The supply shocks, product specific, are the exported emissions from a country to France neighboring countries: Italy, Belgium, Spain, Germany, and the UK. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available. Both the instrument and the endogenous are adapted to include, respectively, only imports from non-OECD (col. 2 and 5) or OECD (col. 3 and 6) countries. Robust standard errors in parentheses clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 11: Emission Intensity, Imported Emissions and Energy Prices

Dep. Var. log(Emissions/Turnover)	OLS	IV	IV	OLS pre-trend	IV pre-trend	IV pre-trend
Energy Prices (in log)	-1.200***	-1.683***	-1.704***	-1.089***	-1.050***	-0.926**
	(0.0560)	(0.199)	(0.264)	(0.0713)	(0.323)	(0.411)
Imported Emissions (in log)			-0.584***			-0.517***
			(0.204)			(0.159)
Time x pre-sample avg. emission intensity (in log)				-0.011***	-0.012***	-0.011***
				(0.002)	(0.002)	(0.003)
Time x pre-sample avg. changes in emission intensity (in log)				-0.0094**	-0.0095**	-0.014***
				(0.005)	(0.005)	(0.005)
Observations	26,103	26,103	26,103	17,274	17,274	17,274
Number of firms	4140	4140	4140	2330	2330	2330
F-test excluded instrument		466.1	18.53		185.8	24.87

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. In columns 3 and 4, we replace size class x year dummies with the log of turnover. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. The instrumental variable for energy prices is a weighted average of industry level fuel prices. The fuel weights, firm specific, are the share of the fuel in total energy use of the firm. The industry-level fuel prices are the median price at the 3-digits industry level. Robust standard errors in parentheses clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure 1: Decomposition of imported emissions, 1997-2014



Note: authors' calculation based on trade flows from the French custom data and emission intensity computed using IEA and WIOD data. These statistics are for all firms in the French manufacturing sector.

Appendixes (for on-line publication)

A. Data Appendix

A1. Data Issues

Sectoral crosswalks IEA-WIOD. The sector nomenclature used by the IEA is different but is mapping well with the WIOD 2013 and WIOD 2016. IEA sectors are clear aggregates of the sectors of the WIOD except for "Iron and steel" and "Non-ferrous metals" of IEA that have to be aggregated to a WIOD sector called "Basic Metals and Fabricated Metal" which corresponds to sec27to28 in WIOD 2013 and to C24 and C25 in WIOD 2016.

The WIOD 2013 and 2016 releases have different number of sectors. The 2013 release sector classification is based on the NACE Rev 1 and contains 35 sectors while the 2016 release is based on NACE Rev 2 and contains 56 sectors. The crosswalk in this case is straightforward and we use the sectoral classification of 2013. This choice is done because relevant emission data from IEA are available only at a rather aggregated sectoral level.

Deflating import values. For each sector and year, we compute a Tornqvist price index following the methodology of Gaulier et al. (2008). The Tornqvist price index is the exact price index for a general Translog production function. We use this index to avoid making strong hypothesis on the substitution between imported goods within a sector.

The Tornqvist price index for imported goods is computed as follows:

$$T_{st} = \sqrt{L_{st}P_{st}},$$

where L_{st} is the geometric Laspeyres price index ($L_{st} = \prod_{k\in s}\left(\frac{p_{kt}}{p_{k0}}\right)^{w_{ks0}}$) and P_{st} is the geometric Paasche price index ($P_{st} = \prod_{k\in s}\left(\frac{p_{kt}}{p_{k0}}\right)^{w_{kst}}$). p_{kt} is the price of imported good k at time t and w_{kst} is the share of imports of product k on total expenditure in sector s ($w_{kst} = \frac{\sum_{ij} M_{ijkt}}{\sum_{ij,k\in s} M_{ijkt}}$). Zero represents the baseline year which is 1994 in our case.

We use unit value of imports of French firms to compute the p_{kt}. However, unit values suffer from outliers, thus we follow the method described in Gaulier et al. (2008) to suppress unrealistic data points where the variation is more or less than 5 times the median variation.

After such outliers are dropped, import prices are computed as follows:

$$p_{kt} = \frac{\sum_{ij} M_{ijkt}}{\sum_{ij} Q_{ijkt}},$$

where M_{ijkt} is the import value in euros of firm i from country j in product k and Q_{ijkt} is the net weight in kilograms.

Deflating current output. Output and value added of French companies has been deflated using sectoral deflators provided by the INSEE. To deflate foreign output, we use data from the social accounts of the WIOD 2013 and 2016 that provides output price index for each country and sector. The additional issue here is that we need to aggregate the price index correctly between WIOD sectors belonging to the same IEA sectors.

The price index of an IEA sector is computed as follows: $P_{jst} = \sum_{k\in s} \frac{\sum_t Y_{jkt}}{\sum_t \sum_{k\in s} Y_{jkt}} P_{jkt}$. In other words, we weight each subsector with their contribution to the sector output during the entire observation periods.

For three countries: Switzerland, Norway, and Croatia, there are no data on output price index. We input the data using the simple mean of contiguous countries. Because WIOD data cover only OECD countries plus BRICS, we need to build a price index for the rest of world. We use a similar approach than for the aggregation at the IEA level. We compute a weighted average of the different countries price index. The weight are the countries' share of total output in a given sector for the entire period.

Missing data and outliers. Switzerland, Norway, and Croatia are not in the 2013 release of WIOD, which covers years before 1999. We impute data from1995 to 1999 by using the value of 2000 values (first year of 2016 release).

Following the end of the Soviet Union, several countries in our analysis: Bulgaria, Romania, and Russia experienced episodes of hyperinflation with a large drop of output at the beginning of the observations period between 1994 and 2000. Consequently, the times series for real output, emission intensity and input-output are chaotic. Therefore, for these countries, we assume that they have the emission intensity of their neighbors: Czech Republic, Slovakia, Slovenia, Estonia, Lithuania, Hungary and Poland. Since in the row data Russia, Bulgaria and Romania have high emission intensity, we apply to them the maximum value of these countries for each sector. Notice that these imputations have little effect on our results as imports from these countries is a tiny fraction of total imports of French companies.

A2. Alternative measure of imported emissions

Our measure of emission intensity assumes that the CO2 emission intensity is the same across products of a given sector s and country j. This is clearly a drastic assumption, especially in light of the heterogeneity in emission intensity across products within the same sector (Barrows and Ollivier, 2018). Data on product level emission intensity that vary by country, sector and years are unfortunately not available.

Sato (2014) collected data from life-cycle analysis of the carbon footprint at the product level in 2006, which are however time- and country-invariant. Therefore, by using these data, we will use the time and country-specific variation in emission intensity.[30] To circumvent this issue, we use the Sato's emission factor to make the IEA data on emission intensity to vary at the product level.

This adjusted measure of emission intensity is:

$$ImpE_{it} = \sum_k \sum_j M_{ijt,k\in s}\, EI_{jt,k\in s} \qquad (1.A2)$$

Same formulas as (1) but $EI_{jt,k\in s}$ is computed differently.

$$EI_{jt,k\in s} = \frac{EI_k}{\overline{EI}_s} DEI_{jst} + IEI_{jst},$$

where EI_k is product level carbon intensity from Misato and $\overline{EI}_s = \frac{1}{n_k}\sum_k EI_{k\in s}$ is the simple average emissions intensity of products produced in sector s. The ratio $\frac{EI_k}{\overline{EI}_s}$ allows combining industry x country emissions intensities with product level emission intensity.

B. Appendix: Decomposition of Imported Emissions and Descriptive Evidence

In this section, we provide details on the decomposition of imported emissions. Note first that imported emissions can be written as follows:

$$ImpE_{it} = M_{it} \sum_s \sum_j \phi_{ijst} EI_{jst}, \qquad (1.B)$$

where M_{it} are total import of firm i, $\phi_{ijst} = M_{ijst}/M_{it}$ is the share of imports coming from sector s and country j and EI_{jst} is emission intensity of the same sector-country pair. Totally differentiating equation (1.B), we obtain a standard decomposition formula:

$$dImpE_{it} = \frac{\partial ImpE_{it}}{\partial M_{it}} dM_{it} + \frac{\partial ImpE_{it}}{\partial \phi_{ijst}} d\phi_{ijst} + \frac{\partial ImpE_{it}}{\partial EI_{jst}} dEI_{jst}\ . \qquad (2.B)$$

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[30] Sato (2014) uses the SITC product nomenclature. We use correspondence tables (SITC-to-CPA) to transpose them in our Statistical Classification of Products by Activity in the European Economic Community (so called CPA) nomenclature. Correspondence tables are available from the base RAMON - Reference And Management Of Nomenclatures from EUROSTAT.

The total change in imported emissions is decomposed into a scale, a composition and a technique effect. The scale effect measures how much increase in imported emissions is due to an increase in the volume of imports. The composition effect measures how much increase in emissions is due to the import of products from sector-country pair with a higher carbon intensity. Finally, the technique effect measures the extent to which imported emission becomes cleaner thanks to technological improvements elsewhere. Developing equation (2.B) gives:

$$dImpE_{it} = \sum_s \sum_j \bar{\phi}_{ijst} \overline{EI}_{jst} \, dM_{it} + \bar{M}_{it} \sum_s \sum_j \overline{EI}_{jst} \, d\phi_{ijst} + \bar{M}_{it} \sum_s \sum_j \bar{\phi}_{ijst} dEI_{jst} \quad (3.B)$$

where $\bar{X}_t = 0.5\,(X_t + X_{t-1})$ and $\mathrm{d}X_t = X_t - X_{t-1}$.We perform the decomposition for each manufacturing firms and then sum each element of equations (3.B) across firms to see what drove change in total imported emissions at the aggregate manufacturing level. As $dImpE_{it}$ is not defined for firms that stop or start importing, there is a gap between change in imported emissions and the sum of scale, composition and technique effect at the aggregate level. This gap represents the net contribution of entry and exit to imported emissions.

The results are plotted in

Figure 1 and are reported in Table 1A for sake of completeness. Table 2B reports the results using the different method described in section A2. The results are very similar and the correction for product level emissions leads as expected to a slightly larger composition effect (+71% rather than +69%).

Table 1B: Decomposition of imported emissions 1997-2014, main method

Component	Change from 1997 to 2014
Entry and Exit	41%
Intensive scale	-34%
Composition	69%
Technique	-42%
Total change	34%
Mt CO2 in 1997	68.1
Mt CO2 in 2014	91.2

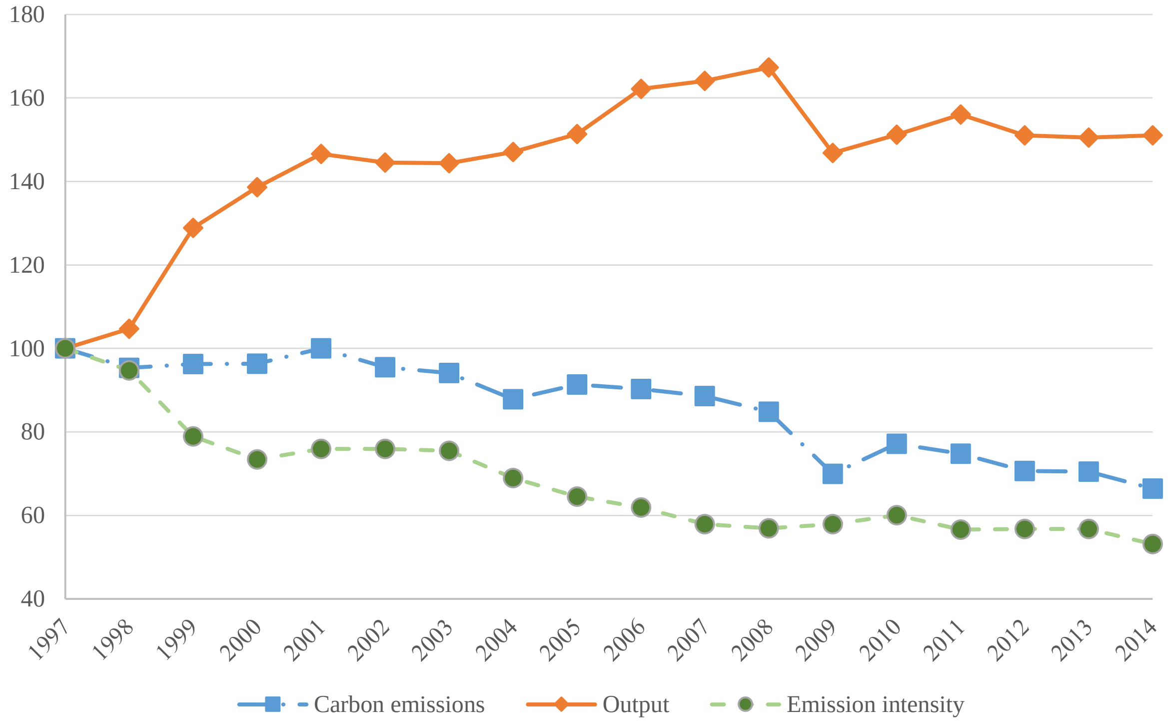
Notes: authors' calculation based on trade flows from the French custom and emission intensity computed using IEA and WIOD data. These statistics are for all firms in the French manufacturing sector.

Table 2B: Decomposition of imported emissions 1997-2014, correcting for product-level emissions (see section A2)

Component	Change from 1997 to 2014
Entry and Exit	38%
Intensive scale	-34%
Composition	71%
Technique	-43%
Total change	33%
Mt CO2 in 1997	69.7
Mt CO2 in 2014	92.8

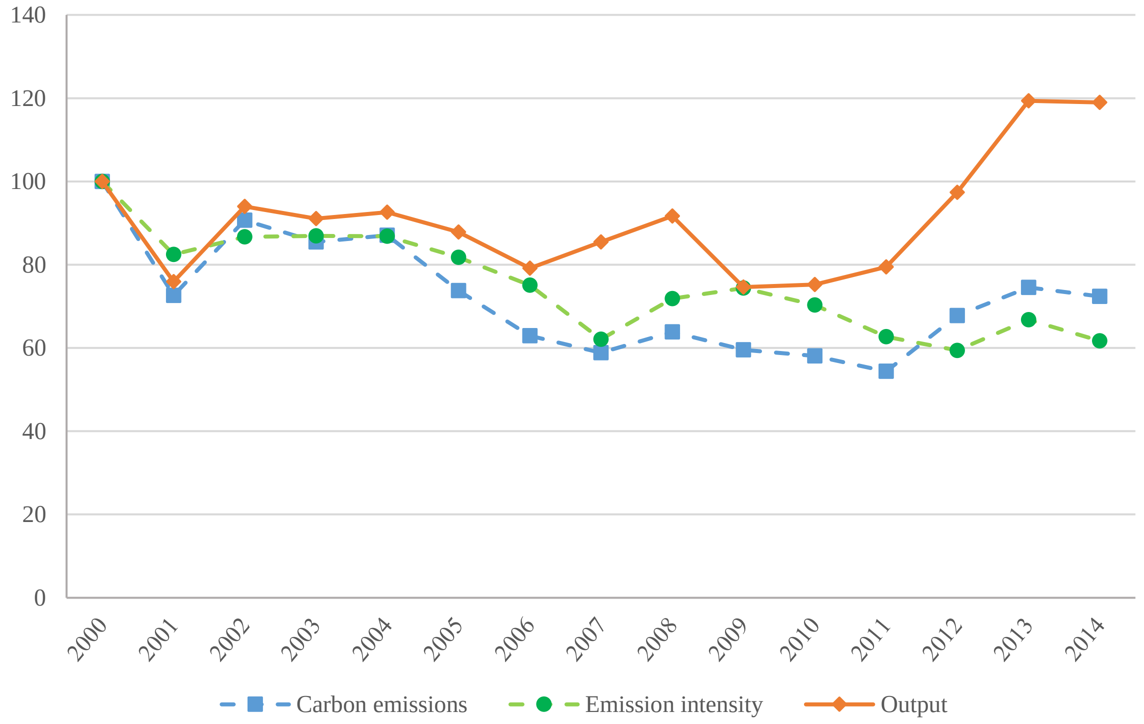
Notes: authors' calculation based on trade flows from the French custom and emission intensity computed using IEA and WIOD data. These statistics are for all firms in the French manufacturing sector.

Figure 1B: Evolution of carbon emissions, output, and average emission intensity of the French manufacturing sector



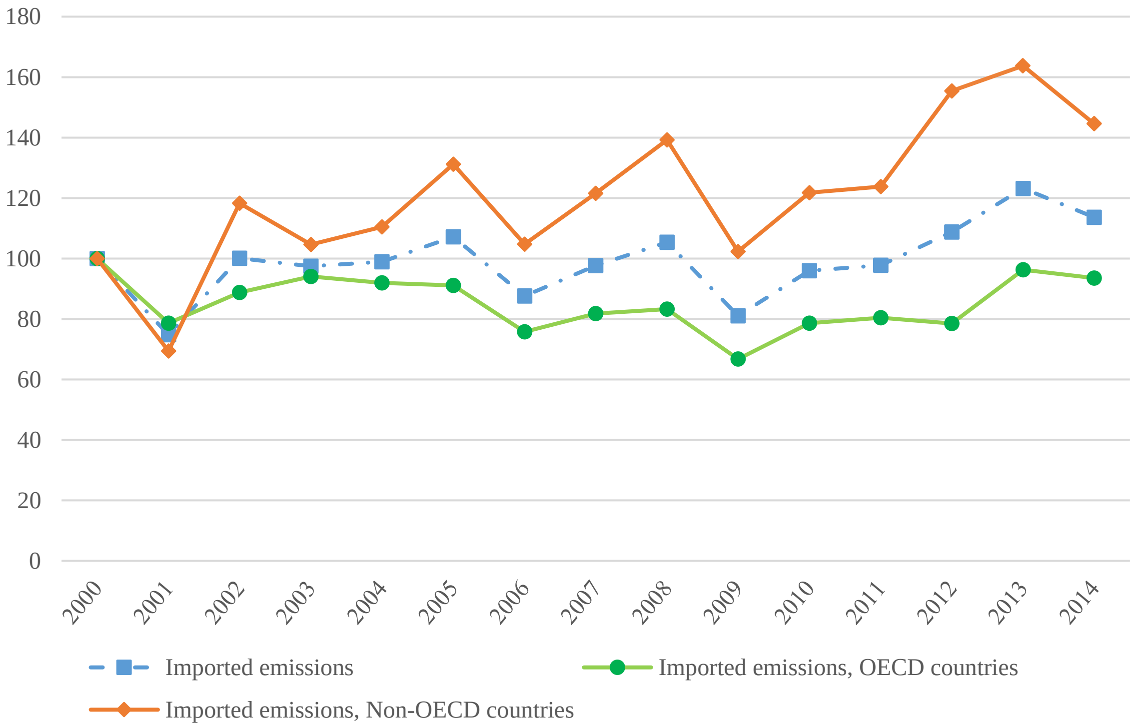
Notes: authors' calculation based on sector data IEA data on carbon emissions from fuel combustion and WIOD data on input-output table and total output. These statistics are for all firms in the French manufacturing sector.

Figure 2B: Evolution of CO_2 Emissions, Emissions Intensity and Output, estimation sample



Notes: Our elaboration on EACEI and FARE-FICUS confidential data.

Figure 3B: Evolution of Imported Emissions, OECD vs. non-OECD



Notes: Our elaboration on Custom confidential data.

Table 3B: Descriptive statistics

	CO2 Emission Int. (tons CO_2/1000 EUR)	CO2 Emissions (tons CO_2)	Turnover (1000 EUR)	Imported Emissions (tons CO_2)	Imports (million euros)	Energy Prices (1000 euros / toe)
Firms always importing (average=2510)						
mean	62.1	2469.1	53625.1	3669.3	9.7	0.657
median	22.9	526.9	21580.5	719.9	2.2	0.630
standard dev.	162.2	6152.6	146339.4	14667.9	34.7	0.329
growth 2012-14 vs. 2000/02	-0.302	-0.184	0.244	0.257	0.180	0.547
Firms always present in the sample (N=281)						
mean	275.7	28300.0	136843	12361.6	24.3	0.566
median	46.5	2995.8	59983	2826.8	7.2	0.552
standard dev.	930.6	119000	351532	41185.6	58.6	0.171
growth 2012-14 vs. 2000/02	-0.413	-0.166	0.279	0.299	0.131	0.649

Notes: our elaboration on EACEI, FARE-FICUS and Custom data. All statistics are unweighted. The growth rates are based on the difference between the moving average of the last three years (2012-2014) and the moving average of the first three years (2000-2002).

C. Appendix: Robustness Checks

Table 1C. Emissions and Imported Emissions, controlling for pretrends

Dependent variable log(Emissions)				
	IV	IV	IV, turnover	IV, turnover
Imported Emissions (in log)	0.136	0.0689	-0.324	-0.578
	(0.129)	(0.131)	(0.485)	(0.704)
Turnover (in log)			0.774	1.096
			(0.587)	(0.855)
Time x pre-sample avg. emissions (in log)	-0.0156***		-0.0110***	
	(0.0014)		(0.0011)	
Time x pre-sample avg. changes in emissions (in log)	-0.00672		-0.0127	
	(0.0043)		(0.0091)	
Observations	24,243	24,243	24,243	24,243
Number of firms	2856	2856	2856	2856
F-test excluded instrument	45.86	44.78	4.518	3.825

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 2C: Emission Intensity and Imported Emissions, different IV

Dep. Var. log(Emissions/ Turnover)		
	IV less exogenous	IV product-destination variation
Imported Emissions (in log)	-0.373***	-0.843
	(0.138)	(1.049)
Observations	35,537	33,504
Number of firms	4962	4591
F-test excluded instrument	62.01	3.301

*Note*s: Only firms always importing are included in the estimation sample. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. Robust standard errors in parentheses clustered at the firm level. In column 1, we use a different and arguably less exogenous shift, namely world exports of all countries except France and countries bordering France towards the countries bordering France (i.e., Germany, Spain, Italy, UK, and Belgium). In column 2, as in Carluccio et al. (2015), we use origin-destination variation in the initial shares and total global exports as a shift. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 3C: Emission Intensity and Imported Emissions, add. controls

Dep. Var. log(Emissions/ Turnover)		
	OLS	IV
Imported Emissions (in log)	-0.0575***	-0.403**
	(0.0063)	(0.183)
Capital per worker (in log)	0.0185***	0.0337***
	(0.0059)	(0.0106)
Value Added per worker (in log)	-0.151***	-0.117***
	(0.0132)	(0.0221)
Observations	35,537	35,537
Number of firms	4,962	4,962
F-test excluded instrument		48.22

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 4C: Emission Intensity and Imported Emissions, energy intensive sectors

Dep. Var. log(emissions/turnover)				
	OLS	IV	IV pretrends	IV pretrends sample
Imported Emissions (in log)	-0.0455	-0.159	-0.0782	-0.183
	(0.285)	(0.191)	(0.154)	(0.158)
Imported Emissions (in log) X	-1.011	-0.579	-0.609*	-0.538
Dummy energy intensive sector	(0.743)	(0.381)	(0.321)	(0.333)
Time x pre-sample avg. emissions (in log)			-0.0160***	
			(0.00184)	
Time x pre-sample avg. changes emiss. (in log)			-0.0142***	
			(0.00432)	
Observations	35,537	35,537	23,507	23,507
Number of firms	4,962	4,962	2755	2755
F-test excluded instrument		23.93	25.73	25.93

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 5C: Emission Intensity and Imported Emissions, rescaling for Value Added

Dep. Var. log(Emissions/ Value Added)		
	OLS	IV
Imported Emissions (in log)	-0.0288***	-0.395**
	(0.00590)	(0.169)
Observations	35,462	35,462
Number of firms	4957	4957
F-test excluded instrument		49.34

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 6C: Emission Intensity and Imported Emissions, firms covered 100% in EACEI

Dep. Var. log(Emissions/ Turnover)		
	OLS	IV
Imported Emissions (in log)	-0.0564***	-0.342**
	(0.0069)	(0.1710)
Observations	30 715	30 715
Number of firms	4488	4488
F-test excluded instrument		51.16

Notes: Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 7C: Emission Intensity and Imported Emissions, weighted by turnover

Dep. Var. log(Emissions/ Turnover)		
	OLS	IV
Imported Emissions (in log)	-0.103***	-0.638***
	(0.00995)	(0.186)
Observations	35,532	35,532
Number of firms	4963	4963
F-test excluded instrument		124.7

Notes: Regressions weighted by turnover. Only firms always importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8C: Emission Intensity and Imported Emissions, all importers

Dep. Var. log(Emissions/ Turnover)				
	OLS	IV	IV, pre-trends	IV, pre-trend sample
Imported Emissions (in log)	-0.0403***	-0.611**	-0.478***	-0.529***
	(0.00418)	(0.282)	(0.176)	(0.192)
Time x pre-sample avg. emission intensity			-0.0168***	
(in log)			(0.00162)	
Time x pre-sample avg. changes in emission			-0.0152***	
intensity (in log)			(0.00542)	
Observations	53,214	53,214	31,368	31,368
Number of firms	9217	9217	4437	4437
F-test excluded instrument		21.41	36.55	36.13

Notes: Firms importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. Robust standard errors clustered at the firm level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 9C: Emission Intensity and Imported Emissions, dynamic model

Dep. Var. log(Emissions/ Turnover)				
	All Importers	All Importers	Always Importers	Always Importers
Imported Emissions (t, log)	-0.267	-0.391	-0.152	-0.257*
	(0.265)	(0.243)	(0.161)	(0.144)
Imported Emissions (t-1, log)	-0.138		-0.17	
	(0.129)		(0.127)	
Cumulative Effect	-0.405		-0.322**	
p-value cumulative effect	0.114		0.0477	
Observations	35 800	35 800	25 795	25 795
Number of firms	6385	6385	3902	3902
F-test excluded instrument	6.795	19.67	15.36	45.71

Notes: All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries. The supply shocks, product specific, are the exported emissions from a country to France neighboring countries: Italy, Belgium, Spain, Germany, and the UK. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available. Robust standard errors in parentheses clustered at the firm level. In columns (1) and (3), each endogenous is instrumented with the corresponding IV, i.e. the current IV and the lagged one. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 10C: Emission Intensity and Imported Emissions, dynamic model

Dep. Var. log(Emissions/ Turnover)

	OLS	IV	IV no lags	IV pretrends	IV pretrends sample
Imported Emissions (in log)	-0.045***	-0.466**	-0.395**	-0.527**	-0.402**
	(0.0067)	(0.226)	(0.175)	(0.265)	(0.187)
Imported Emissions (in log), t-1	-0.024***	0.0884		0.109	-0.0186
	(0.006)	(0.198)		(0.221)	(0.193)
Time x pre-sample avg. emission intensity (in log)				-0.014***	
				(0.0019)	
Time x pre-sample avg. changes in emission intensity (in log)				-0.00911	
				(0.0063)	
Cumulative Effect	-0.069***	-0.378**	-0.395***	-0.418*	-0.421**
Observations	24,851	24,851	24,851	17,614	13,495
Number of firms	3807	3807	3807	2397	2069
F-test excluded instrument		7.711	31.32	5.879	8.747

Notes: Firms importing are included in the estimation sample. All rows include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. All columns include firm fixed-effects, industry (2-digits) x year dummies, region x year dummies, and size class x year dummies. The instrumental variable defined in the main text is a weighted average of supply shocks from all countries, except France and neighboring countries of France: Italy, Belgium, Spain, Germany, and the UK, towards all countries except France and neighboring countries of France. The weights, firm-specific, equal the product share of the firm total imports in the first three years of trade data available and are adjusted for the average emission intensity of the product. In the dynamic model of columns (2)-(5), each endogenous is instrumented with the corresponding IV, i.e. the current IV and the lagged one. Robust standard errors clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 11C: Imported Emissions and Energy Prices

Dependent var. log(Imported Emissions), except in column (5) where it is the share of imported on domestic emissions in log

	OLS	IV	IV, non-OECD	IV, OECD	IV, share
Energy Prices (in log)	-0.0441	0.127	0.234	-0.114	0.919***
	(0.0356)	(0.349)	(1.011)	(0.339)	(0.252)
Observations	26,103	26,103	17,684	25,926	26,103
Number of firms	4140	4140	3105	4115	4140
F-test excluded instrument		466.1	242.6	464.5	466.1

Notes: All columns include firm fixed-effects, industry (2-digits) x year dummies, and region x year dummies. The instrumental variable is a weighted average of industry level fuel prices. The fuel weights, firm specific, are the share of the fuel in total energy use of the firm. The industry-level fuel prices are the median price at the 3-digits industry level. Robust standard errors in parentheses clustered at the firm level. * p < 0.1, ** p < 0.05, *** p < 0.01.

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