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July 2019

Centre for Climate Change Economics and Policy Working Paper No. 187
ISSN 2515-5709 (Online)

Grantham Research Institute on Climate Change and the Environment Working Paper No. 165
ISSN 2515-5717 (Online)

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Suggested citation:
Dechezleprêtre A, Gennaioli G, Martin R, Muûls M and Stoerk T (2018) Searching for carbon leaks in multinational companies. Centre for Climate Change Economics and Policy Working Paper 187/Grantham Research Institute on Climate Change and the Environment Working Paper 165. London: London School of Economics and Political Science

Searching for carbon leaks in multinational companies*

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July 2019

Abstract

Does unilateral climate change policy cause companies to shift the location of production, thereby creating carbon leakage? In this paper, we analyse the effect of the European Union Emissions Trading System (EU ETS) on the geographical distribution of carbon emissions of multinational companies. The empirical evidence is based on unique data for the period 2007-2014 from the Carbon Disclosure Project. Because they already operate from multiple locations, multinational firms should be the most prone to carbon leakage. Our data includes regional emissions of 1,122 companies, of which 261 are subject to the regulation. We find no evidence that the EU ETS has led to a displacement of carbon emissions from Europe towards the rest of the world, including in countries with no climate policy in place and within energy-intensive companies. Overall, the paper suggests that modest differences in carbon prices between countries do not induce carbon leakage.

*We are grateful to seminar and conference participants at LSE, EAERE, AERE, and EUI FSR Climate for helpful comments and suggestions. Financial support from the European Union Seventh Framework Programme under grant agreement no. 308481 (ENTRACTE), the Grantham Foundation for the Protection of the Environment, and the UK Economic and Social Research Council through the Centre for Climate Change Economics and Policy is gratefully acknowledged. All errors and omissions are our own. Stoerk's contribution to this research only reflects his personal views and not necessarily those of the European Commission.

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1 Introduction

With the implementation of the European Union Emissions Trading System (EU ETS) and a range of other policies supporting the deployment of low-carbon technologies such as renewable energy, the European Union is widely perceived as the vanguard of climate change policy globally. However, this unilateral set of policies has raised concerns that EU governments are threatening the international competitiveness of Europe-based companies, in particular in carbon and energy intensive industries. This paper analyses a unique dataset to explore whether multinationals have displaced their carbon emissions from Europe towards the rest of the world when subject to carbon pricing. In a free-trade world economic model, the adoption of unilateral climate policies which increase the price paid by firms for their carbon emissions relative to their foreign competitors would lead to a pollution-haven effect (Copeland and Taylor (2004); Levinson and Taylor (2008)): countries with relatively weaker regulations specialise in the production of carbon-intensive products in which they have a newly acquired competitive advantage, and subsequently export these back to "virtuous" countries. The idea that higher energy prices due to climate policy may result in some relocation of energy-intensive industries is supported by empirical evidence that countries more abundantly endowed with energy resources specialize in energy-intensive sectors vis-a-vis otherwise comparable countries (Gerlagh et al., 2015). The relocation of economic activity toward less-regulated regions means that the policy is not only ineffective from a climate change point of view, as emissions are likely relocating with production rather than being reduced, but also costly from an economic point of view, by destroying jobs and economic activity in the more strictly regulated countries. This issue has been referred to as "carbon leakage" and has attracted a lot of attention both on the policy arena and in the recent literature (see Branger and Quirion (2014) and Fowlie and Reguant (Forthcoming) for recent reviews).

In this paper, we explore this hypothesis using a unique panel dataset tracking the geographical distribution of carbon emissions of 1,122 multinational companies. Multinational companies, with operations across a wide range of jurisdictions, might be particularly reactive to environmental regulations that impose higher production costs in a given location by shifting production to less regulated regions. Our data comes from the Carbon Disclosure Project (CDP), a non-profit data collection initiative established by the investment community to collect climate change-relevant data at the level of individual businesses, with the aim of understanding the exposure of companies to future climate change policies. The unique feature of the CDP data is that emissions for multinational businesses are broken down by country or geographical regions. Hence, we are able to study whether multinationals subject to the EU ETS reduce emissions in one location only to increase them elsewhere. Specifically, we compare emissions in Europe with emissions occurring outside Europe within the same company between 2007 (the beginning of the CDP project) and 2014. On the basis of this data, we do not find any evidence that the EU ETS caused leakage of carbon out of Europe. This conclusion does not only emerge for the average firm in our sample but also for various sub-samples, including - most importantly - firms that are deemed by the European Commission to be particularly at risk of carbon leakage because they are highly carbon-intensive and/or trade-exposed.

The EU ETS was launched in 2005. It currently covers 31 countries across Europe (all 28 European Union Member States plus Iceland, Liechtenstein and Norway), 14,000 power stations and industrial facilities, representing roughly 40% of the EU's total greenhouse gas emissions, which are regulated according to their main activity, such as combustion of fossil fuel, cement production or paper and pulp production. An important feature of the EU ETS is that not all carbon-emitting installations operating in these sectors are regulated, in order to minimize administrative costs. Activity-specific capacity criteria determine which installations are included in the EU ETS and which installations are exempt from the regulation. As in any cap-and-trade system, EU ETS installations are required to surrender at the end of each year as many permits as they emit greenhouse gas (GHG) emissions. Prior to the compliance date, installation operators can freely trade permits with each other (as well as with financial intermediaries and private citizens). The EU ETS has been divided into a number of trading phases, with successively more stringent emissions caps for each phase. For the first phase, the emissions cap was fixed at 2,298 Mt CO2e per year. Phase 1, running from 2005 to 2007, was insulated from later phases by prohibiting banking and borrowing of permits across the phase boundary. Phase 2 (2008 –2012) and Phase 3 (2013 –2020) allow firms to bank unused permits for later use, as well as a limited form of borrowing against future emissions reductions. With Phase 3, the coverage of the EU ETS also became broader and previously unregulated sectors such as aviation and the production of aluminum became regulated. Since 2005, the spot price has varied between €0 and €30. The average price between 2005 and 2015 was around €10. The price of forward contracts has remained steadily above the spot price, though, suggesting firms are taking the progressive stringency of the cap into account. Firms that operate regulated installations can then make abatement and investment decisions according to the carbon price revealed in the market. It is important to note that the spectre of leakage continues to influence key legislation such as the most recent EU Directive 2018/410 on the EU ETS from March 2018.[1]

This paper relates to the literature that seeks to understand the impact of unilateral climate change policies on carbon leakage (see Sato and Dechezleprêtre, 2015 and Dechezleprêtre and Sato, Forthcoming for recent reviews).[2] This literature has so far mainly used ex-ante model simulation strategies to assess the quantitative impacts of unilateral climate change policy, typically using Computable General Equilibrium (CGE) models (see Carbone and Rivers, 2017, for a review of the CGE-based literature). These studies have estimated a wide range of leakage rates associated to different emission reduction targets under the Kyoto Protocol. Dröge et al. (2009) reports rates between 5 and 25%, while Lanz and Rausch (2011) find central estimates in the range of 15–30%. However, some studies find

[1]Provision 10, for instance, states that "Experience gathered during the operation of the EU ETS has confirmed that sectors and subsectors are at risk of carbon leakage to varying degrees". Free allowance allocations are a direct consequence of this concern.

[2]See also Sato (2013) for a comprehensive review of the literature that seeks to measure the carbon content of trade.

negative leakage rates due to spillover effects (e.g. Barker et al., 2007) while some others report leakage rates above 100% implying that emission reduction efforts in one region are more than fully compensated by increased emissions in other regions, for example because production shifts to less-technologically advanced (and thus more carbon-intensive) regions. Overall, these results are very sensitive to model assumptions and suggest large levels of uncertainty. These average carbon leakage rates also hide important differences across sectors, due to varying carbon intensities of production, abatement potential, transport costs, product differentiation and other parameters. For example Fischer and Fox (2012) simulate the impact of a $14/ton CO2 tax in the U.S. based on a multi-region CGE model. They find an overall leakage rate of 7 percent, but the iron and steel and nonferrous metals experience leakage rates of respectively 58% and 57%. Generally, the steel sector, characterized by both high product differentiation and abatement potential, has been found to experience higher leakage rates (see Sato, 2013).

Compared to the extensive CGE literature, few empirical studies have sought to estimate the magnitude of the effect of climate change regulation on carbon leakage. Aichele and Felbermayr (2012) analyse the impact of carbon emissions reduction commitments taken under the Kyoto Protocol on bilateral trade based on a matching methodology to deal with self-selection of countries into Kyoto. They find that signing of the protocol caused a 14% reduction in exports among Kyoto signatory countries, suggesting that some carbon leakage is happening. There is large heterogeneity in the effect across sectors, with energy-intensive industries like iron and steel, non-ferrous metals and chemicals most affected by competitiveness issues. Aichele and Felbermayr (2015) go beyond the previous paper and analyse the impact of Kyoto commitments directly on the carbon content of sectoral bilateral trade flows. They find that Kyoto commitments have increased embodied carbon imports by committed countries from non-committed countries by around 8% and the emission intensity of their imports by about 3%. Again, the impact is heterogeneous across sectors, with industries such as basic metals, nonmetallic mineral products, or paper and pulp experiencing the largest rates of carbon leakage.

In the absence of carbon pricing policies in most countries, changes in relative energy prices have provided an interesting source of variation to analyse the impact that climate change policy may have on production location and trade flows. Aldy and Pizer (2015) use variation in state-level industrial energy prices across time and in the energy mix across industries to estimate how net imports change in response to energy prices, with a detailed panel of US state-level manufacturing production covering 450 sectors between 1979 and 2005. They find that the effect of energy price on net imports is statistically indistinguishable from zero when averaging across all sectors, but find evidence that net imports are more sensitive to energy prices in sectors with higher energy intensity, including iron and steel, chemicals, paper, aluminum, cement and bulk glass. The magnitude of the effect is small, however, with an increase of between 0.1% and 0.8% in net imports for these energy-intensive industries, from a hypothetical $15 per ton CO_2 price imposed unilaterally in the US. Sato and Dechezleprêtre (2015) specify an energy price gap between two trading partners and examine its influence on bilateral trade flows using a panel dataset covering 42 countries and 62 manufacturing sectors over 1996-2011 and a gravity model framework. They find on average that a 10% increase in the energy price gap increases bilateral imports by 0.2%, and that overall, changes in relative energy prices across time explain only 0.01% of the variation in trade flows. Sato and Dechezleprêtre (2015) use their estimates to evaluate the degree to which stricter carbon pricing policies in Europe would affect trade patterns and find that a €40-65/tCO_2 price of carbon in the EU ETS would increase Europe's imports from the rest of the world by around 0.04% and decrease exports by 0.2%. Ben-David et al. (2018) use variation in a composite index of environmental regulatory stringency across countries to ask whether environmental regulation induces firms to shift polluting activities abroad. They find that firms that hail from countries with stricter environmental laws emit less greenhouse gas at home and more abroad.

A few studies have sought to empirically assess the impact of the EU ETS on carbon leakage (see Martin et al., 2016 for a broad review of the ex-post empirical evidence on the impact of the EU ETS on regulated firms). Most studies use trade flows as the outcome variable. Naegele and Zaklan (Forthcoming) analyse the impact of the EU ETS on carbon emissions embodied in traded goods and on trade value using data from the Global Trade Analysis Project (GTAP). They devise a measure of climate policy stringency at the sector level by combining GTAP with data from the EU Transaction Log (EUTL), the EU repository of data on emissions, allowances and transactions in the EU ETS. This allows them to determine which goods are produced by sectors regulated under the EU ETS and the (direct and indirect) costs of emissions associated with these sectors. They find no evidence that the EU ETS caused any increase in net imports (either in value or in terms of embodied carbon emissions). The point estimates are close to zero and quite precisely estimated, so they can rule out an increase of more than 0.3% at the 95% confidence level. These findings confirm earlier insights on specific sectors. Branger et al. (2016) focuses on the cement and steel sector while Sartor (2013) looks at the aluminum sector, and none of these papers find any evidence of carbon leakage due to the EU ETS carbon price. Finally, using data for French manufacturing firms, Colmer et al. (2016) find no impact of the EU ETS on import of intermediate goods by regulated companies.

Analyzing whether impacts of the EU ETS on competitiveness would lead to the downsizing of businesses in Europe, Martin et al. (2014a) and Martin et al. (2014b) survey close to 800 manufacturing firms in six EU countries. In order to protect industry from potential relocation risks, the European Commission designed a list of sectors deemed at risk of carbon leakage, and companies operating in these sectors qualify for free allowances while others progressively have to resort to auctioning. The authors find that there is on average no risk of businesses downsizing their activity due to having a price on carbon. However, this risk varies across sectors, and firms regulated under the EU ETS report a significantly higher propensity to reduce their operations in the EU by up to 10 percent in response to future carbon pricing than non-EU ETS firms. The authors propose a distribution scheme for carbon permits allocation in the EU ETS that would take into account the differences in relocation risk.

Other studies have used firm-level data to investigate the impact of the EU ETS on foreign direct investment, which could be viewed as indicative of carbon leakage. Koch and Basse Mama (2016) use data from Germany and Borghesi et al. (2016) focus on Italy. Like us, these papers hypothesize that multinational firms might be particularly prone to relocation of emissions following the implementation of unilateral carbon pricing policies. Contrary to this paper, they don't have geographically disaggregated carbon emissions data but instead analyse whether the EU ETS led regulated firms to increase investment in plants in unregulated (or lower regulated) countries. Borghesi et al. (2016) find that the EU ETS had a small positive effect on the number of new subsidiaries abroad, but a larger impact on production taking place in foreign subsidiaries (the intensive margin), especially in trade-intensive sectors. Koch and Basse Mama (2016) also find evidence that the EU ETS encourages outward FDI of German multinationals. However, the effect is concentrated on a small subset of firms that are less capital intensive and therefore likely to be more geographically mobile.

Our paper contributes to this literature by providing new evidence on the link between EU ETS regulation and carbon leakage. Thanks to the unprecedented data collection effort by the Carbon Disclosure Project (CDP), we are able to track firm level CO_2 emissions by geographical region for 8 years since 2007. Exploiting information on the country of origin of carbon emissions, we can directly assess the carbon leakage hypothesis by comparing trends of multinational firms' CO_2 emissions in Europe relative to non-European countries, depending on whether they are regulated by the EU ETS or not. The novelty of the research lies in our ability to track greenhouse gas emissions within multinational companies in all jurisdictions in which they operate. To the best of our knowledge we are the first to be able to do this.

The rest of the paper is structured as follows. The next section describes in detail the different datasets used, in particular the one obtained from CDP. Section 3 presents the empirical methodology and Section 4 discusses the results. We conclude in Section 5.

2 Data and descriptive statistics

2.1 Main dataset

We construct an unbalanced panel of firms for the period 2007-2014 by combining three different data sources. First, data on annual firm level carbon emissions are obtained from the Carbon Disclosure Project (CDP), an NGO acting on behalf of over 600 institutional investors. CDP asks listed companies to disclose geographically-disaggregated information on carbon emissions.[3] The CDP data are unique: as far as we know, the CDP data are the only consistently available data source to track the geographical distributions of carbon emissions *within* multinationals. Second, we obtain data on turnover, assets, number of employees and sector of activity of these companies from ORBIS, one of the largest global financial firm-level database provided by Bureau Van Dijk under a commercial license. Finally, we use the European Union Transaction Log (EUTL) to identify companies that own at least one installation regulated under the EU ETS.[4]

Identifying which multinational company is regulated by the EU ETS is not straightforward because of the challenge in assigning EUTL installations to CDP companies. The challenge, therefore, lies in matching EU ETS *installations* to *multinational companies*. The most consistent way to perform this matching is to use the Bureau van Dijk company identifier, which we construct from the CDP data using the ORBIS database. This subsection explains the steps we perform for the EU ETS treatment coding.

[3]The CDP has recently started to also include non-listed firms in its survey.

[4]For some countries in our sample, the company registration numbers of the installation operators were obtained directly, either from national emissions trading registries or from the European Union Transaction Log (EUTL), the EU body to which national registries report. For the other countries, a combination of exact and approximate text matching methods were used to establish a link between firm data and regulatory data. This was complemented by further manual searches, and extensive manual double-checking.

1. Find subsidiaries: For each of the multinationals, we extract a list of its subsidiaries. For each subsidiary, we extract the share that the parent multinational owns in the subsidiary.[5].

2. Keep subsidiaries for whom the multinational owns at least 20% of the shares: Based on the distribution of the ownership share of the multinationals in their subsidiaries, we select 20% as the threshold below which we drop a subsidiary. There are two reasons for this choice: firstly, it comes from the distribution of the percentage of all shares in a subsidiary held by a multinational. There are three clear peaks in this distribution: at 100%, at 50.01%, and close to 0%. We think it reasonable to consider a parent company as treated if its ownership of a subsidiary is substantial, which includes the first two peaks but not the last. To not make the cutoff too conservative at 50.01%, we include all subsidiaries that are owned with at least 20%. Note, however, that a change in this threshold would not meaningfully impact the results due to the tiny number of subsidiaries that are owned with an ownership share between 20% and 50%.

3. Merge to EUTL database: We then merge the dataset of remaining subsidiaries as well as the parent multinationals to the EUTL database of all EU ETS-regulated installations. We do this in a two-step procedure, matching first the subsidiaries and then the multinationals themselves to the EUTL database based on the Bureau van Dijk identifier in ORBIS. Additionally, we manually check for consistency of the merge. A multinational is then defined as treated by the EU ETS if at least one of its subsidaries or the multinational itself owns an installation included in the EU ETS. In other words, we code a CDP firm as treated if it controls more than 20% of any EU ETS installation. Overall, 261 multinationals

[5]The number of subsidiaries for each multinational is capped at 1000 due to computational constraints. To transform verbal information from the ORBIS database into percentages, we replace 'wholly owned' with 100%, and majority-owned by 50.01% (as suggested by Kalemli-Ozcan et al. (2015)) If a firm's shares are listed as exceeding a percentage of a given size, we code it as that percentage plus 0.01 percentage points, and likewise for shares listed as being lower than a certain percentage. For example, an entry of '>50%' is coded as '50.01%'. The observations that contained 'PG' and 'NG' could not be given an unambiguous quantitative meaning and are thus coded as missing. This concerns only few subsidiaries of few multinational firms.

are treated in our sample.[6]

As shown in Figure 1, the number of observations in the CDP grows in the initial years of our sample, and then remains at about 600 throughout. The overall sample consists of 1,122 companies, 261 of which are regulated under the EU ETS.

Figure 1: Number of Observations over the Period 2007-2014

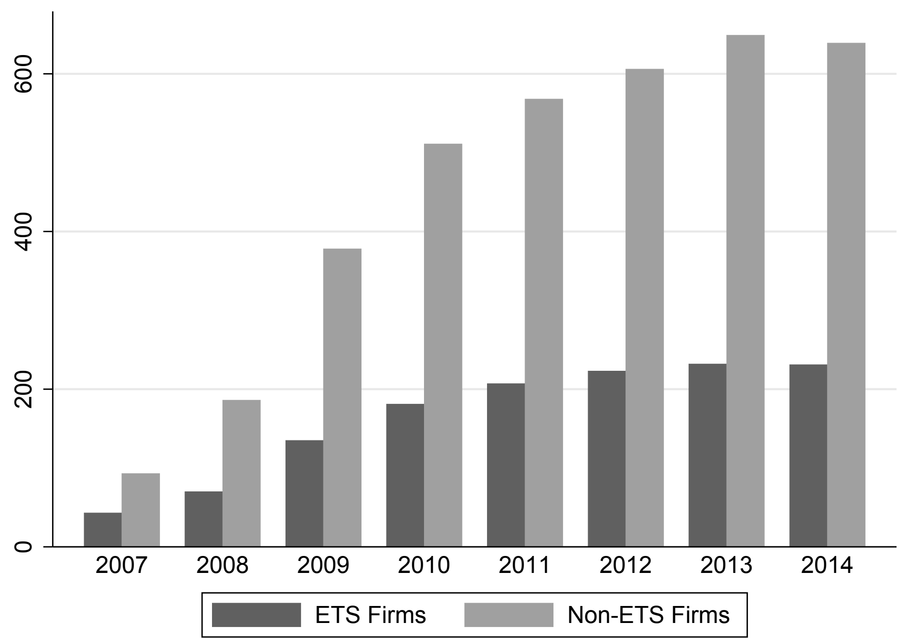
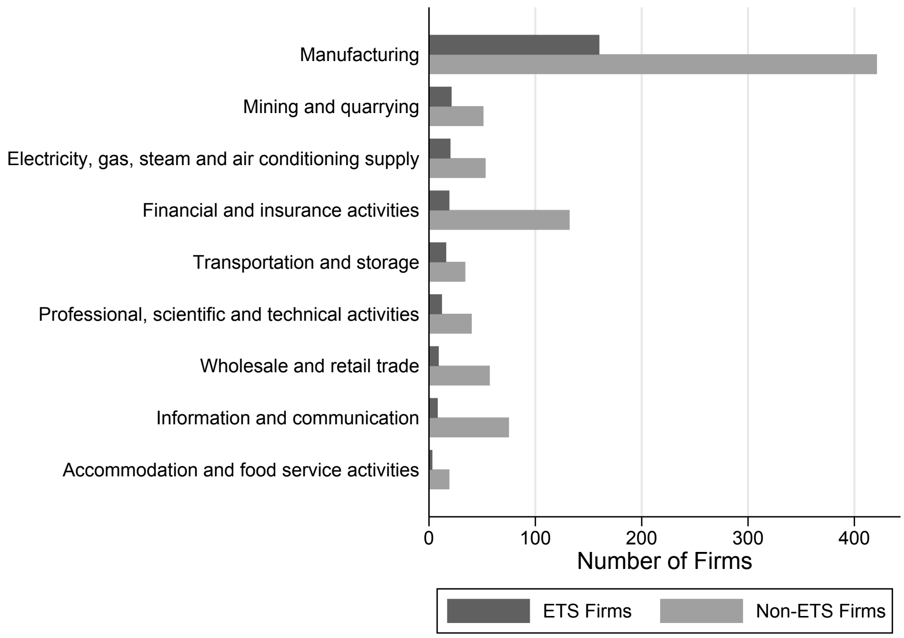


Figure 2 displays the sectoral distribution of the companies in our sample, sorted by the number of EU ETS firms in a sector. The firms we observe are those that voluntarily answer the CDP questionnaire and therefore represent a subset of listed firms. The majority of these companies are from the manufacturing sector, with other companies mainly operating in the

[6] We believe that the way we code EU ETS multinationals is the most reasonable way of doing so: it is the most transparent, and it allows for a clear selection of what subsidiary is a significant enough subsidiary to induce the parent company to be treated by the EU ETS. It is possible, however, to redo the treatment coding in reversed order. That is, we can first match all EU ETS installations from the EUTL to ORBIS, and then look up their parent companies. We have found this merge to be less transparent and clean, and found that the number of EU ETS treated firms differs greatly depending on the level of ownership (owning company or immediate shareholder, domestic ultimate owner and global ultimate owner). In contrast to our preferred way of coding the treatment status, however, this method does not allow to use information on the intensity of ownership, i.e. the percent of all shares of a subsidiary owned by a parent company. In the limit, this method therefore risks coding a CDP multinational as treated when one of their subsidiaries owns a minuscule share of an EUTL installation. Our results, however, are robust to coding CDP firms as treated in this manner.

banking and financial, ICT , and utilities sectors. As expected, the majority of EU ETS companies in the sample operate in the manufacturing, mining and quarrying, and utilities sectors.

Figure 2: Distribution of Companies across Industries



It is important to keep in mind, however, that it is activities that are regulated under the EU ETS, not economic sectors, even if they sometimes closely overlap (e.g., cement production). As a consequence, companies operating in virtually any sector of the economy can be regulated by the EU ETS if, for example, they produce energy on-site using carbon-emitting fuels such as gas, coal or oil. This explains why we find EU ETS-regulated companies in sectors such as financial and insurance activities or retail trade. In terms of the size of regulated EU ETS companies, we note that we focus on multinational firms. By definition, these firms a larger in size compared to the average EU ETS-regulated company. On the other hand, it is precisely large multinational firms that are most prone to leakage, so results based on our sample should give an upper bound for the effect of the EU ETS on leakage in the average EU ETS-regulated firm.

2.2 Selection issues in the emissions data

With non-mandatory participation in the CDP carbon reporting program and a focus on listed companies, concerns of selection bias might arise. There is an extensive literature studying the likelihood of companies to report their emissions in voluntary surveys. For example, some recent contributions (Reid and Toffel, 2009; Brouhle and Harrington, 2009; Matsumura et al., 2011) have shown that companies operating in cleaner sectors are more likely to report their environmental activity. This is also true for companies performing better relative to others in their sector. Reporting also increases with the proportion of reporting firms in the same sector. However, such issues are less of a concern with the CDP data. Firstly, while the CDP survey is not mandatory, firms have an additional incentive to participate because CDP acts as an agent for a group of large investment firms. This setup introduces a somewhat different reputational driver: refusal to take part could send a negative signal to potentially important investors and sources of finance for a firm. Second, participating firms are given the choice to be featured in the outward facing CDP report or only to be included in background data and confidential reports to investors. Besides, there are some concerns about the consistency of survey quality across firms and over time and the lack of verification of survey answers. However, for the purpose of this study, these issues are only of concern if they vary systematically between EU ETS and non-EU ETS firms, and across regions within each firm.

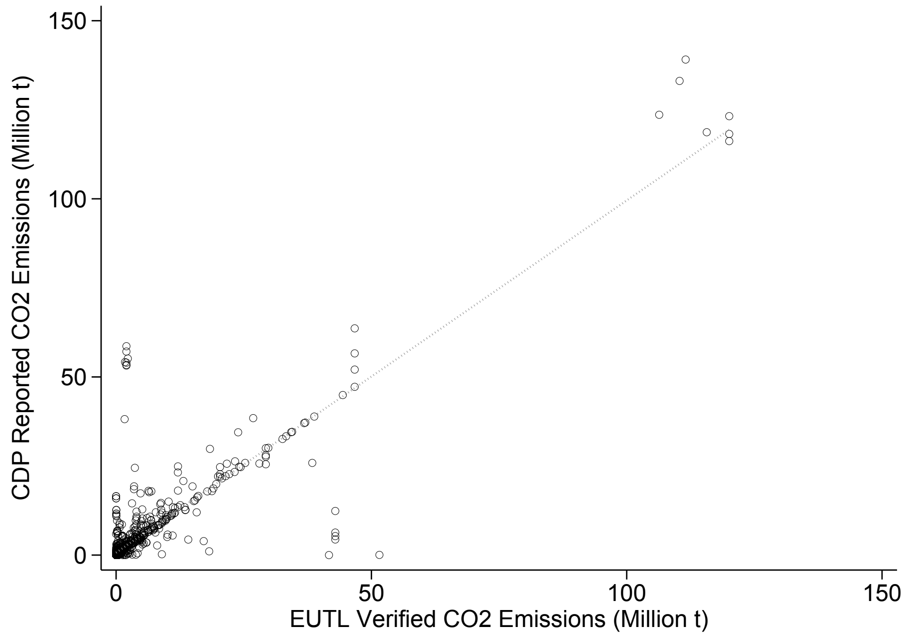
2.3 Consistency of the CDP emissions data

One remaining concern with the CDP emissions data is that they might not contain enough signal to detect a leakage effect because of noise. Carbon reporting is a recent development, and different reporting methodologies currently coexist. While the CDP recommends the use of the WRI/WBCSD GHG protocol, multinationals are allowed to follow different reporting methodologies (Bellassen and Stephan, 2015). To assess the consistency of the outcome data, we use the CDP emissions data for the European subsidiaries of EU ETS multinationals and correlate it to the verified emissions data obtained from the EUTL. While invariably coarse, we expect to find a clear and significant relationship between the two. To do this, we use the verified emissions for each EUTL installation belonging to a multinational firm and aggregate them at the multinational level. We weight the emissions by the percentage of the shares that the multinational owns in a subsidiary. To illustrate: a multinational that owns 50% of all shares of a subsidiary would be assigned 50% of that subsidiary's emissions. This weighting strategy corresponds to the guidelines in the Climate Change Reporting Framework used by the CDP survey that instructs multinationals to weight greenhouse gas emissions in joint ventures by ownership percentage. We then correlate these verified emissions to all reported CDP emissions, summed to the multinational-Europe level.

Figure 3 below shows that there is a strong correlation of 0.88, and a slope coefficient of close to 1. In other words, the CO_2 emissions reported in the CDP survey are an accurate reflection of the underlying reality. The correlation is also statistically significant: while there are some obvious outliers, a linear regression of reported emissions on the verified emissions with cluster-robust standard errors, where multinationals are the units of clustering, yields a t-statistic of 13.71. We interpret this as an additional indication that the quality of the CDP data is sufficient for our analysis.

Nevertheless, note that there is still substantial noise in the CDP data for the following reasons: (i) the matching process between CDP companies and EU ETS-regulated installations is inevitably an approximation; (ii) not all companies report greenhouse gas emissions alike and they need to be consistently applying existing guidelines; and (iii) in a few cases, multinationals only report total European emissions in the CDP survey, rather than emissions broken down by countries, making it difficult to compare emissions on a like for like basis.

Figure 3: Consistency of CDP Reported CO_2 Emissions Data



Note: Corr: 0.88; Coeff: 0.99; t-stat: 13.71 (cluster-robust SEs)

3 Methods

There is a range of potential definitions and types of carbon leakage.[7] The main contribution of this paper is that it is the first to study leakage *within* firms. Leakage from the EU is understood here as the amount of CO_2 emissions relocated within multinational firms in the short run as a direct consequence of the introduction of climate policies within the EU. The regulation imposes higher costs in some locations and firms shift production to less regulated regions. In Appendix A we introduce this more formally, but the main hypothesis is that multinational companies with operations across a wide range of jurisdictions might be more

[7]The IPCC (2007) defines it as "the increase in CO_2 emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries". Matthes (2008) distinguishes between two forms of leakage: investment leakage and operational leakage. The former follows in the medium-to-long run from the decision of firms to not expand their production facilities or failure to reinvest in the regulated region (the EU in this case). The latter describes the short-term reaction of production being stopped or decreased in the EU and relocated to other countries with no carbon pricing. This paper, focusing on short term emissions changes relates to operational leakage.

likely than single-country firms to react through carbon leakage because they have already incurred the cost of setting up a subsidiary in a foreign country.

The carbon leakage hypothesis is explored by looking at two types of indices of firm-level changes in emissions. First, we compare the growth rate of a firm's EU and non-EU (RoW) emissions:

$$g_{it}^{R} = \frac{CO2_{it}^{R} - CO2_{it-1}^{R}}{0.5\left(CO2_{it}^{R} + CO2_{it-1}^{R}\right)} \tag{1}$$

where $R \in \{EU, RoW\}$. An indication for leakage would be the finding of negative emission growth in the EU ($g_{it}^{EU} < 0$) that goes along with positive emission growth in the rest of the world ($g_{it}^{RoW} > 0$). If firms subject to climate regulation also have stronger positive demand shocks or weaker productivity shocks than non- or less-regulated control firms, then leakage would imply that EU emissions grow slower that RoW emissions.

Secondly, we examine firm-level changes in the share of emissions from within the EU:

$$\Delta s_{it}^{EU} = s_{it}^{EU} - s_{it-1}^{EU} \tag{2}$$

where $s_{it}^{EU} = \frac{s_{it}^{EU}}{s_{it}^{EU} + s_{it}^{RoW}}$ is the share of EU[8] CO_2 emissions for firm i at time t. If carbon was systematically leaking from the EU within MNEs, we would expect Δs_{it}^{EU} to be on average negative, and even more so for firms most targeted by climate policies such as the EU ETS. An advantage of looking at the EU share is that it neutralizes the effect of non-climate policy shocks that affect all production locations of a firm uniformly.

The effects of the EU ETS are then examined by running regressions of the form:

$$\Delta s_{it}^{EU} = \beta_1 ETS_i + \beta_2 timestep_{it} + \gamma CDPvintage_t + \eta industry_i + \tau X_{it} + \epsilon_{it} \tag{3}$$

where ETS_i is an indicator variable equal to 1 for firms regulated by the EU ETS and

[8] For convenience we describe emissions borne in countries that are part of the EU ETS as EU emissions although in practice we measure them depending on the year of the policy and the countries at that time, such that emissions in Iceland, Liechtenstein and Norway are included since 2008.

X_{it} is a vector of control variables. $Timestep_{it}$ is a variable that counts the number of years since a multinational last responded to the CDP survey, and $CDPvintage_t$ are fixed effects for each year of the CDP survey. $industry_i$ are sector fixed effects (which - since we estimate the impact on growth rates of emissions - are equivalent to adding sector trends in a fixed effects specification).

Note that unfortunately the CDP data only covers years that have followed the introduction of the EU ETS.[9] However, we can assume that CO_2 emissions are complementary to fixed capital investments. Therefore, there is likely to be an adjustment period in response to changes in the businesses environment (such as the introduction of the EU ETS) such that the effects of a policy change could be observed for an extended period.

The main parameter of interest is β which is expected to be strictly negative if the carbon leakage hypothesis is true. The estimation of β could be affected by any source of unobserved heterogeneity between EU ETS and non-EU ETS firms. For instance, ETS firms by definition have to be located in the EU (at some point) whereas this is not the case for non-ETS firms. Moreover, ETS firms are mostly manufacturing firms or power plants. We address this issue by estimating equation (3) for a number of different subsets of the data. First, the sample is restricted to firms reporting non-zero emissions both inside and outside the EU, although not necessarily at the same point in time. Second, we only look at firms with non-zero EU emissions in the base year (t-1). Third, we focus on firms with non-zero EU emissions in the base year (t-1) *and* non-zero non-EU emissions at some point in our sample. In addition, the previous specifications are repeated restricting the sample to manufacturing firms.

We further refine the analysis, running the regressions on a sub-sample of firms that belong to sectors deemed "at risk of carbon-leakage" by the European Commission. Such sectors exceed certain thresholds in terms of carbon or trade intensity or both. Leakage

[9]Findings by Colmer et al. (2016) based on a French dataset suggest that the effect of the EU ETS only set in from Phase 2 onwards, i.e. after 2008. Appendix C.3 contains a tentative difference-in-differences specification that draws on these findings by considering the years prior to 2008 as a pre-treatment period.

effects would be expected to be particularly strong in such sectors (see Appendix B for a list of those sectors).

4 Main results

Table 1 reports the descriptive statistics for all 1,122 companies in the sample. There are 9 firms for which there is no operating revenue data available in Orbis, 16 firms for which total assets are missing and slightly more than a hundred firms for which employment is missing. The average share of CO_2 emissions within Europe across our sample is 34%.

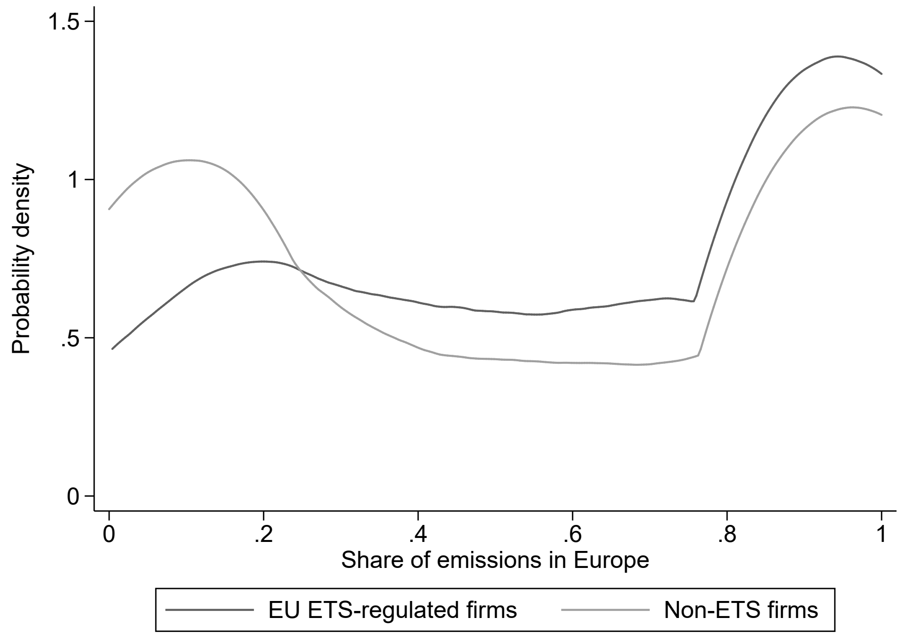
Table 1: Descriptive Statistics

	(1) Mean	(2) Stand. Dev.	(3) N. firms	(4) Obs.	(5) Source
CO_2 Emissions within Europe (Million t CO_2e)	1.26	9.86	1,122	3,802	CDP
CO_2 Emissions outside Europe (Million t CO_2e)	3.07	12.37	1,122	3,802	CDP
Share of CO_2 Emissions within Europe	34%	39%	1,122	3,802	CDP
Δ Share of EU emissions	-0.01	0.09	1,122	3,802	CDP
Operating Revenue (Million Euros)	12940.85	24503.95	1,113	3,778	ORBIS
Total Assets (Million Euros)	55180.93	198541.37	1,106	3,745	ORBIS
Employees (in Thousands)	44.11	94.28	1,000	3,433	ORBIS

In Table 2, we compare ETS and non-ETS companies using simple t-tests. Not surprisingly, ETS firms emit more both in European and in non-European countries. They are on average characterized by a higher turnover, a higher number of employees and higher assets. About 60% of the emissions of ETS-firms tend to be located in Europe. While this number is slightly lower for non-ETS firms, a look at the full firm-level distribution of the share of emissions in Europe, displayed in Figure 4, shows the large overlap across both groups of multinationals, suggesting that the non-ETS firms in our sample are in fact a relevant control group. The figure displays our preferred sample which includes only non-ETS multinationals that report positive emissions in the European Union in the CDP survey.

Figure 5 provides a graphical summary of our main findings relating to the growth of emissions. It reports the joint bi-variate distribution of the growth in CO_2 emissions in

Figure 4: Comparability of treated and control firms



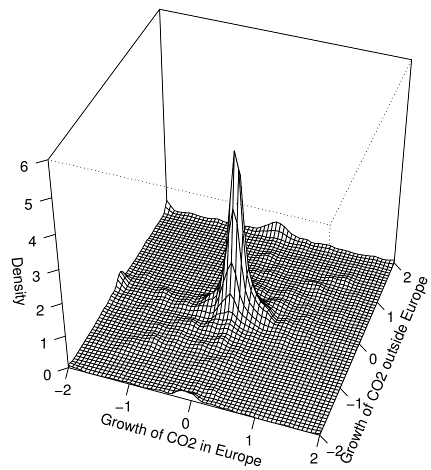
the EU versus the Rest of the World (RoW) at the level of firms.[10] Panel (a) shows the distribution for all firms with non-zero EU emissions in the base year. Panel (b) reports only ETS firms. Panel (c) overlays contour plots from both distributions. Looking first at Panel (a) we see that the distribution is concentrated primarily around zero implying that most firms do not change their carbon emissions very much. There is also a notable mass of firms with positive growth in both EU and RoW emissions. Panel (b) suggests that emissions growth is more heterogeneous in ETS firms with a more uniform distribution. However, there is little evidence of such firms simultaneously reducing EU and increasing RoW emissions. Negative emissions growth in the EU is rather associated with negative emission growth in the RoW as well. Hence, this indicates either genuine emissions reduction efforts globally or a decline of economic activity in these sectors rather than leakage activity.

Figure 6 shows the share of CO_2 emissions in Europe over the period 2007-2014 for

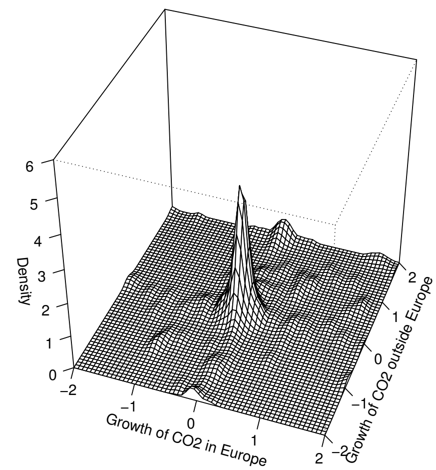
[10]See equation 1.

Figure 5: The Joint Distribution of Changes in CO_2 Emissions - EU vs RoW

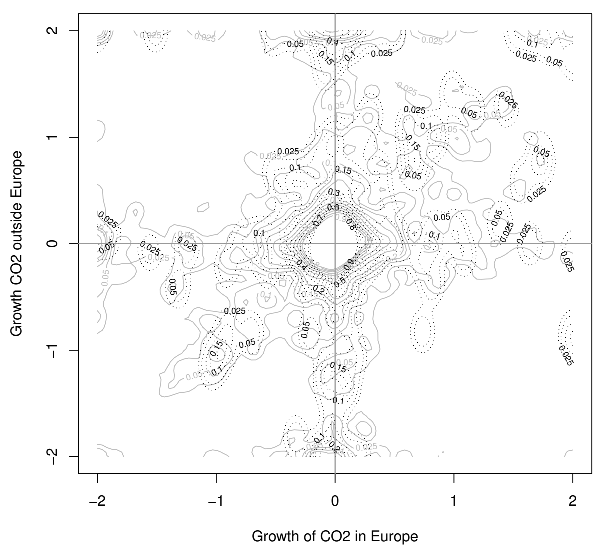
(a) Firms with Positive CO_2 in EU in Base Year



(b) ETS firms

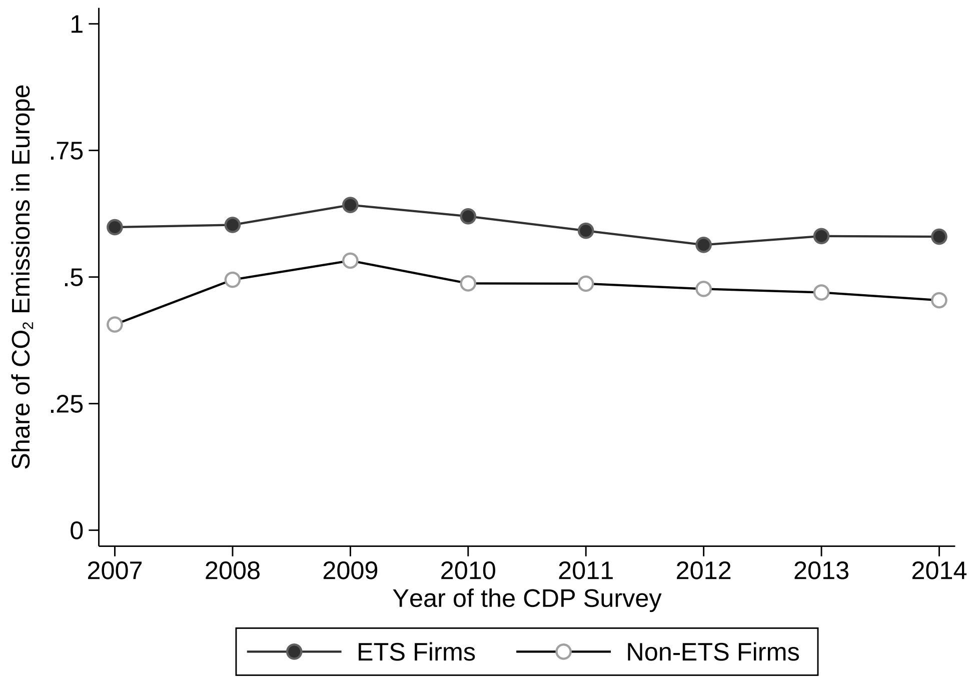


(c) Overlaid Contour Plots



the full sample of ETS and non-ETS firms respectively. It is consistent with the evidence presented in Table 2, showing that ETS firms generate a larger share of emissions in Europe compared to non-ETS firms. From 2007 to 2008, non-ETS firms display a slight increase in this measure compared to a constant share experienced by ETS companies. However, on average the two groups follow a similar trend and the gap between them remains fairly stable over the period 2007-2014. If anything, we observe that non-EU ETS firms increase their share of emissions in Europe over time, while that share remains stable for EU ETS firms.

Figure 6: Share of CO_2 Emissions in Europe for ETS and non ETS Firms



Turning to the results relative to the share of EU emissions, Table 3 reports the estimates of equation (3) with the dependent variable being the change in the share of EU emissions. Panel A reports the results for all firms in our sample, Panel B restricts the sample to manufacturing firms only and Panel C presents the results for firms in sectors considered at risk of carbon leakage according to the classification provided by the European Commission (Emissions Trading Directive 2009/29/EC). As discussed above, the European Commission determines if a sector can be considered at risk by looking at its carbon and trade intensity.

Moving through the columns of Table 3, we impose different restrictions regarding regional presence of firms. Column 1 includes all firms. In column 2 we only include companies reporting positive emissions *both* in EU and in RoW, although not necessarily at the same time. Column 3 includes only observations from companies with positive EU emissions in the first period for which the company answered the CDP survey. Finally, column 4 includes firms with positive EU emissions in the first period *and* non-zero in the RoW at some point over the sample. The sub-samples created by cycling through both the panels and columns of Table 3 serve two purposes. Firstly, by restricting the sample to manufacturing firms or firms with non-zero EU emissions in their first year we make the control group of non-ETS firms more similar to firms regulated by the ETS.[11] Secondly, by focusing on sectors supposedly at risk of carbon leakage or firms with both EU *and* RoW emissions we investigate the potential heterogeneity of leakage effect between firms. Specifically, we would expect leakage effects to be more severe in groups deemed at risk of carbon leakage by the European Commission.

Looking at the different point estimates we see that the coefficient on the ETS indicator is insignificant throughout Table 3. Furthermore, it is estimated to be very small, compared to the -0.09 average decrease in the share of CO_2 emissions in Europe for EU ETS firms. The point estimate is slightly positive for all the subsamples, but we can never reject the hypothesis that it is equal to zero. The highest positive coefficient estimate - though still insignificant and small - in all Panels is in column 4, i.e. for companies that report positive CO_2 emissions in an EU ETS-regulated country in the first period and positive CO_2 emissions in RoW at some point. This is the group of firms for which a leakage effect would be most expected. Therefore we do not find any evidence of a leakage effect, which would be characterized by a negative and statistically significant coefficient.

In column 2 we find that our point estimate is positive, but it is not significant at the 10% level. The effect is thus statistically not distinguishable from zero. It is instructive, however, to ask what a positive coefficient would imply, hypothetically speaking. Two possible explanations spring to mind. Firstly, as discussed in more detail in Appendix A, there might be offsetting regional specific productivity shocks that are much stronger than the carbon

[11]A company can only be regulated by the EU ETS if it has emissions within the EU.

price shocks implied by the ETS. Secondly, we have to bear in mind that the European Commission is classifying sectors at risk of leakage in order to target risk mitigating policy measures. Specifically, sectors “at risk” are receiving freely allocated emission permits. Hence a positive effect could imply that this policy is particularly successful to an extent that borders on “reverse leakage”. At any rate, no our results indicate a zero effect.

Table 2: ETS vs. non-ETS Firms

	ETS Firms	Non-ETS Firms	Difference
Panel A: All Firms (N= 1,122)			
CO_2 Emissions within Europe	6.02	0.13	5.89***
(Million tons CO_2e)	(21.48)	(0.63)	[0.00]
CO_2 Emissions outside Europe	3.96	0.53	3.43***
(Million tons CO_2e)	(11.58)	(3.52)	[0.00]
Share of CO_2 Emissions within Europe	60.6%	50.8%	0.10***
	(0.33)	(0.38)	[0.00]
Δ Share of EU emissions	-0.01	-0.02	-0.01
	(0.08)	(0.13)	[0.20]
Operating Revenue	24529.39	9158.31	15371.07***
(Million Euros)	(34899.22)	(21778.59)	[0.00]
Total Assets	84100.34	53494.79	30605.55*
(Million Euros)	(248432.1)	(206842.6)	[0.09]
Employees	63.06	38.91	24.15***
(in Thousands)	(81.81)	(118.10)	[0.01]
Panel B: Manufacturing Firms (N=571)			
CO_2 Emissions within Europe	1.86	0.05	1.81***
(Million tons CO_2e)	(6.69)	(0.21)	[0.00]
CO_2 Emissions outside Europe	2.74	0.25	2.49***
(Million tons CO_2e)	(9.96)	(1.24)	[0.00]
Share of CO_2 Emissions within Europe	55.1%	39.0%	0.16***
	(0.32)	(0.35)	[0.00]
Δ Share of EU emissions	-0.01	-0.02	0.01
	(0.09)	(0.14)	[0.53]
Operating Revenue	21299.14	7303.6	13995.68***
(Million Euros)	(31461.65)	(16142.29)	[0.00]
Total Assets	32327.31	8658.97	23668.35***
(Million Euros)	(57594.08)	(18766.13)	[0.00]
Employees	62.73	26.06	36.68***
(in Thousands)	(78.74)	(43.18)	[0.00]
Panel C: Manufacturing Firms at Risk of Carbon Leakage (N=328)			
CO_2 Emissions within Europe	1.56	0.05	1.50***
(Million tons CO_2e)	(3.70)	(0.24)	[0.00]
CO_2 Emissions outside Europe	2.39	0.28	2.10***
(Million tons CO_2e)	(7.00)	(1.39)	[0.00]
Share of CO_2 Emissions within Europe	54.5%	36.3%	0.18***
	(0.32)	(0.35)	[0.00]
Δ Share of EU emissions	-0.005	-0.02	0.1
	(0.09)	(0.14)	[0.43]
Operating Revenue	19212.07	7610.67	11601.39***
(Million Euros)	(30016.68)	(17505.87)	[0.00]
Total Assets	28766.74	8936.22	19830.00***
(Million Euros)	(57924.38)	(19922.42)	[0.00]
Employees	54.80	26.20	28.59***
(in Thousands)	(69.12)	(44.17)	[0.00]

NOTES: Means and standard deviations are reported in parenthesis. The p-value for the difference is reported in square brackets in column (3) and taken from a two-sided t-test with equal variances. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Firms at risk of carbon leakage are CDP companies operating in sectors deemed at risk of carbon leakage by the European Commission. Manufacturing firms are firms coded as "C-Manufacturing" in the NACE Rev.2 Main Section classification. The number of firms N in Panels A-C refers to the total number of firms in the sample. Not all firms report all firm level characteristics. Sample is restricted to firms that report positive emissions in Europe when first reported in CDP.

Table 3: Regressions of the share of emissions in EU

Dependent variable:	Δ Share of EU emissions			
	(1)	(2)	(3)	(4)
Sample composition:	All	EU>0 RoW>0 any	EU>0 in t=1	EU>0 in t=1 RoW>0 any
Panel A: All Firms				
ETS	-0.000548	0.00324	0.00865	0.00950
	(-0.12)	(0.54)	(1.48)	(1.43)
Observations	3802	2589	2441	2134
Number of firms	1122	676	683	568
R^2	0.00470	0.00877	0.00962	0.0132
Panel B: Manufacturing Firms				
ETS	0.000480	0.00320	0.00820	0.00952
	(0.07)	(0.40)	(0.97)	(1.03)
Observations	2007	1496	1305	1196
Number of firms	571	388	360	318
R^2	0.00741	0.0113	0.0133	0.0147
Panel C: Manufacturing Firms at Risk of Carbon Leakage				
ETS	0.000189	0.00217	0.00674	0.00754
	(0.02)	(0.22)	(0.63)	(0.66)
Observations	1147	830	706	656
Number of firms	328	220	201	180
R^2	0.0073	0.0100	0.0119	0.0130

NOTES: t statistics in parentheses. Significance levels are indicated as ***p< 0.01, **p< 0.05, *p< 0.1. Column 1 includes all firms in the sample. Column 2, firms that have positive emissions in both EU and RoW in some year. Column 3, firms with positive EU emissions in the first period for which the company answered the CDP survey (t=1). Column 4 with positive EU emissions in t=1 and non-zero RoW emissions at some point over the sample.

5 Extensions and robustness

In this section, we present a range of robustness checks and extensions which together lead us to believe that the null results represents a true estimate for no leakage.

5.1 Robustness to treatment assignment

One concern is measurement error on treatment assignment. Since we match data on multinational firms from the CDP dataset to EU ETS installations via ORBIS to obtain treatment status, there is likely to be some amount of noise that this process introduces for treatment assignment. Mis-assignment of treated installations to multinationals will bias our estimates towards zero.

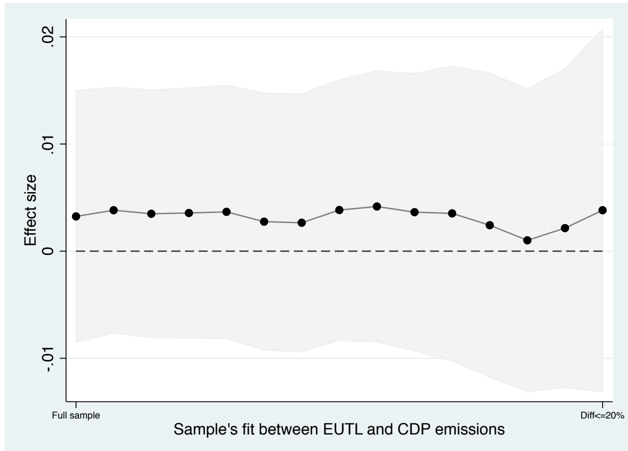
To rule out measurement error on treatment assignment as explanation for our null result, we re-estimate the treatment effect of our preferred specification from Table 3(A-2) for subsamples for which we have information about the quality of the fit. This information is the consistency between the CDP and EUTL emissions datasets as reported in Figure 3, using the following train of thought: the less noise in the matching process to assign EU ETS installations to CDP multinationals, the closer the reported emissions from both datasets. Since we observe these emissions, we can increasingly restrict the quality of the fit to study how the estimated effect size changes with the quality of the match. If measurement error on treatment is a concern, the effect size would change as we increasingly restrict the subsample.

Figure 7 shows that this is not the case. Instead, the point estimate for the effect size is remarkably stable for all subsamples starting from the full sample (the leftmost observation), all the way to the most restricted subsample that only considers observations for which the CDP and the EUTL emissions differ by at most 20%[12]. Our interpretation is that miss-assigned treatment status is unlikely to explain the null result of no carbon leakage as a result of the EU ETS.

As an additional robustness check, we also run the same specification, but this time

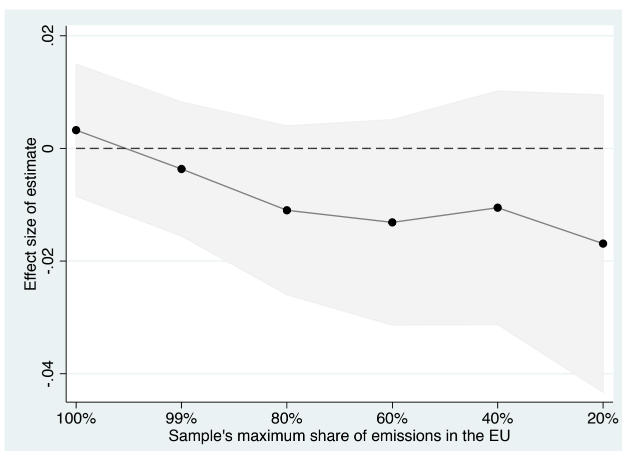
[12]The confidence intervals, in light grey, widen as expected due to the reduced sample size.

Figure 7: Estimated effect size and the quality of the match



Note: The figure reports the effect size for the specification in Table 3, Panel A, Column (2). Each point represents the specification for a different subsample based on the fit between the CDP and EUTL emissions data.

Figure 8: Estimated effect size and the share of EU emissions



Note: The figure reports the effect size for the specification in Table 3, Panel A, Column (2). Each point represents the specification for a different subsample based on the maximum share of emissions of the firm in the EU.

restricting the sample to firms that have a maximum share of EU emissions. Starting with the whole sample, the result remains insignificant when we reduce the sample to firms that do not have more than 20% of their emissions in the EU.

5.2 Climate policy stringency in non-European jurisdictions

The effect of the EU ETS on carbon leakage might be affected by the stringency of climate policy in the other regions where EU ETS-regulated multinationals operate. In particular, companies that face a less stringent climate policy in other regions in which they operate might have a higher incentive to displace emissions outside of Europe in response to the EU ETS. In order to explore this potential source of heterogeneity in the results, we use the EBRD's Climate Laws, Institutions and Measures Index (CLIMI) that measures the stringency of climate policy regulation in each country. First, we compute an average CLIMI for different regions in the world, by weighting the CLIMIs of each country within a given region with its GDP levels in the initial period. This regional measure displays significant variation: Europe is the region with the most stringent climate regulation, while the region corresponding to former USSR as well as North America score very low in our weighted Index. Oceania's and Asia's CLIMIs are close to the world average, driven by Australia and China in the respective regions. Both countries increased their policy effort to tackle climate change at the end of our sample period (before Australia abolished its carbon tax in 2014).

Based on these, we construct a company-specific CLIMI Index. We weigh the CLIMIs of the non-European world regions in which the company operates. The weight used for each region is computed as the share of the company's emissions in that region in the first year for which geographically disaggregated emissions are reported for the firm[13]. Each firm's specific measure captures the extent to which the individual company is exposed to a stringent regulation outside Europe. In this section, we explore whether the share of EU emissions is influenced by the climate stringency companies face outside the EU in regions they are active in, depending on whether they are EU ETS regulated companies or not. We test this hypothesis by estimating an augmented version of equation (3):

[13] The share is computed only relative to the emissions that each company produces outside Europe.

$$\Delta s_{it}^{EU} = \beta_1 ETS_i XCLIMI_i + \beta_2 ETS_i + \beta_3 CLIMI_i + \beta_4 timestep_{it} + \gamma CDPvintage_t + \eta industry_i + \tau X_{it} + \epsilon_{it}$$

where $CLIMI_i$ is the company-specific weighted CLIMI and $ETS_i XCLIMI_i$ is the interaction between the ETS dummy and the company-specific weighted CLIMI. A significant coefficient on the interaction term would indicate the presence of heterogeneous effects of the ETS on companies which are more or less exposed to stringent climate regulation outside Europe. Table 4 below reports the results of this exercise where we estimate this specification for different sub-samples. Column 1 presents results for the whole sample of firms emitting outside the EU, the second column focuses on the manufacturing sector, and column 3 narrows the sample even further to firms that are in the manufacturing sector and in a sector defined as at risk of carbon leakage. We find that being active in non-EU regions with less stringency on climate policy does not increase the likelihood to reduce the share of EU emissions. The coefficient is negative but not statistically significant at conventional levels.

5.3 Other robustness checks

We have conducted a number of variations of the analysis reported in Table 5 for robustness purposes. First, we use the sample of firms as in column (2) of Table 3 and we repeat the estimation of equation 3 including logged control variables such as capital stock, turnover and the number of employees. Column (1) of Table 5 shows that our main results are not altered by the inclusion of control variables. Results are also not altered when failing to control for the number of years since the last report - $timestep_{it}$ in equation 3 (column 2). In column (3) we consider only year-on-year changes in carbon emissions and remove

Table 4: Regressions of the share of emissions in EU - Climate Stringency

Dependent variable:	Δ Share of EU emissions		
	(1)	(2)	(3)
Sample composition:	All	Manufacturing	Manufacturing + at Risk of CL
ETS x CLIMI Index	0.0297	-0.0758	-0.117
	(0.52)	(-0.74)	(-0.89)
ETS	-0.0133	0.0308	0.0453
	(-0.57)	(0.75)	(0.87)
CLIMI Index	0.0497	0.0827	0.0383
	(1.38)	(1.24)	(0.44)
ln (Revenue)	0.0137**	0.0228	0.0156
	(2.35)	(1.50)	(0.97)
ln (Assets)	-0.00684	-0.0174	-0.00883
	(-1.58)	(-1.36)	(-0.75)
ln (Employment)	-0.00282	-0.0000767	-0.00469
	(-1.07)	(-0.02)	(-0.80)
Observations	2393	1433	793
Number of firms	623	371	210
R^2	0.0148	0.0165	0.0115

NOTES: *t* statistics in parentheses. Significance levels are indicated as * 0.10 ** 0.05 *** 0.01. Only firms that have positive emissions in both EU and RoW in some year are included. Column 1 is equivalent to Table 3's column 2 but adds balance sheet controls. Column 2 does not control for the number of years since the last observation and column 3 only includes observations where the Δ Share of EU emissions is for one year.

observations where the number of years since the last report is greater than 1. None of these robustness checks alter our finding of the absence of a leakage effect due to the EU ETS.

In column (4) of Table 5 we augment the preferred specification with an interaction between the variable ETS and the yearly spot price of ETS allowances. The interaction term becomes our variable of interest which is now time variant. This enriched specification allows us to include company fixed effects and obtain a within company estimate of the average effect of a change in the ETS spot price on the share of EU emissions for ETS companies. Our main results hold under this alternative specification.

Table 5: Regressions of the share of emissions in EU - Robustness

Dependent variable: Sample composition: EU>0 + RoW>0 in some year	Δ Share of EU emissions (1)	(2)	(3)	(4)
Panel A: All Firms				
ETS	-0.00305	-0.00250	-0.00546	0.219
	(-0.47)	(-0.39)	(-0.82)	(1.07)
ETS*spot price				-0.000674
				(-0.37)
spot price				0.000624
				(0.49)
ln (Revenue)	0.0137**	0.0137**	0.0145**	0.0191
	(2.29)	(2.30)	(2.32)	(0.61)
ln (Assets)	-0.00681	-0.00672	-0.00857*	-0.0250*
Observations	2393	2393	2275	2393
Number of firms	623	623	612	623
R^2	0.0138	0.00751	0.00774	0.0103
Panel B: Manufacturing Firms				
ETS	-0.000366	0.000136	-0.00282	0.494
	(-0.04)	(0.02)	(-0.32)	(1.43)
ETS*spot price				0.000782
				(0.32)
spot price				-0.000192
				(-0.11)
ln (Revenue)	0.0241	0.0238	0.0277*	-0.0322
	(1.50)	(1.49)	(1.69)	(-0.87)
ln (Assets)	-0.0188	-0.0188	-0.0220	-0.00962
	(-1.39)	(-1.39)	(-1.62)	(-0.45)
ln (Employment)	0.000665	0.00102	-0.00101	0.0125
	(0.14)	(0.21)	(-0.21)	(0.84)
Observations	1433	1433	1356	1433
Number of firms	371	371	363	371
R^2	0.0157	0.00737	0.00944	0.0207
Panel C: Manufacturing Firms at Risk of Carbon Leakage				
ETS	-0.000917	-0.00147	-0.00437	0.149
	(-0.09)	(-0.15)	(-0.38)	(0.43)
ETS*spot price				-0.0000850
				(-0.02)
spot price				0.000436
				(0.15)
ln (Revenue)	0.0176	0.0177	0.0304*	-0.172*
	(1.10)	(1.10)	(1.81)	(-1.70)
ln (Assets)	-0.00983	-0.00961	-0.0153	0.0755
	(-0.84)	(-0.81)	(-1.39)	(0.72)
ln (Employment)	-0.00506	-0.00529	-0.0103	0.0192
	(-0.89)	(-0.91)	(-1.61)	(0.57)
Observations	793	793	745	793
Number of firms	210	210	205	210
R^2	0.0111	0.00841	0.00937	0.0104
Control for length of Δ	YES	NO	Δ=1 year	YES
Company Fixed Effects	NO	NO	NO	YES

NOTES: t statistics in parentheses. Significance levels are indicated as * 0.10 ** 0.05 *** 0.01. Only firms that have positive emissions in both EU and RoW in some year are included. Column 1 is equivalent to Table **??**'s column 2 but adds controls for logged revenue, assets and employment obtained from balance sheet data. Column 2 does not control for the number of years since the last observation and column 3 only includes observations where the Δ Share of EU emissions is for one year. Column (4) includes an interaction between the ETS dummy and the yearly ETS spot price, and includes company fixed effects.

6 Conclusion

This paper uses a unique dataset of within-firm carbon emissions data to study the distribution of carbon emissions of multinational firms across countries and over time. We focus on the concern that EU climate policy, particularly its flagship EU Emissions Trading System could lead to carbon leakage, i.e. firms could re-locate polluting activities to non-EU locations in response to being subjected to the EU ETS. Using both exploratory data analysis and regression analysis, and looking at a wide range of sub-samples and specifications we cannot find any evidence for carbon leakage in our data. Our estimation strategy cannot necessarily reveal the causal effect of the EU ETS on leakage as we cannot rule out that region-specific productivity shocks might confound the effects of the EU ETS. However, our results suggest that carbon leakage due to the EU ETS is unlikely to have been an economically meaningful concern until 2014.

Why are the effects of the EU ETS on carbon leakage so small that they cannot so far be statistically detected? The evidence presented here is based on multinational companies that would be expected to be the first to react to unilateral climate change regulations by shifting production and emissions to less-regulated jurisdictions. A first possibility is that the EU ETS, by widely allocating emission permits to carbon-intensive and trade-exposed industries for free, is successfully preventing leakage effects. Indeed, Martin et al. (2014a) argue that the European Commission has been handing out free permits more generously than necessary. A second possibility is that the statistically insignificant effects identified thus far simply reflect the lack of stringency of the EU ETS. The price of carbon in the European market has fluctuated between 0 and 30 euros per tonne since its introduction, spending most of the time in the lower range of this interval. While regulation that does not lead to carbon leakage should be favored, it is likely that the threats posed by climate change will require more stringent regulations going forward than the EU ETS experience analyzed here, and therefore more likely to lead to leakage. However, the regulatory gap could also narrow in the future with emerging economies such as China implementing more stringent climate policy. At present, we can conclude that modest differences in climate policy stringency across countries do not seem to induce carbon leakage, even among multinational companies which can easily shift production and emissions across jurisdictions. An important question for future research is to understand how large these differences can be before carbon leakage starts becoming an issue (and in which sectors), and how climate policies should be adjusted as other countries' regulations evolve.

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Appendix

A A simple model of carbon leakage

This sections introduces a simple model to make precise our definition of Carbon Leakage. We consider firms producing a final good Q. To produce Q firms can invest capital K_R in two regions $R \in \{EU, RoW\}$. Capital inputs translate into final output according to a CES form:

$$Q = \left[(A_{EU} K_{EU})^{\frac{\gamma-1}{\gamma}} + (A_{RoW} K_{RoW})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}$$

where A_{EU} and A_{RoW} are region specific productivity shocks. Suppose that carbon emissions are a linear function of capital: $CO2_R = \rho K_R$ for $R \in \{EU, RoW\}$. For simplicity suppose that capital (user) costs r are uniform across regions. However, there is a charge τ_{EU} for emitting carbon in the EU and an even higher charge τ_{ETS} for ETS regulated firms. For a given quantity of output Q cost minimization implies the following cost function:

$$C(Q, r, \tau) = Qc(r, \tau) = Q \left[\left(\frac{\rho\tau + r}{A_H} \right)^{1-\gamma} + \left(\frac{r}{A_F} \right)^{1-\gamma} \right]^{\frac{1}{1-\gamma}}$$

where we assume for simplicity that firms always invest in both locations.

Emissions in each location are then given by:

$$CO2_{EU} = Q A_{EU}^{\gamma-1} \left(\frac{\rho\tau + r}{c(r, \tau)} \right)^{-\gamma}$$

$$CO2_{RoW} = Q A_{RoW}^{\gamma-1} \left(\frac{r}{c(r, \tau)} \right)^{-\gamma}$$

Final output demand is described by a simple log linear form:

$$Q = \Lambda^{\eta-1} P^{-\eta}$$

where Λ is a firms specific demand shock. Profit maximization implies markup pricing

$$P = \mu c(r, \tau)$$

where $\mu = \frac{1}{1-\frac{1}{\eta}}$

Equilibrium output is consequently determined by

$$Q = \Lambda^{\eta-1} (\mu c(r, \tau))^{-\eta}$$

Hence:

$$CO2_{EU} = \Lambda^{\eta-1} \mu^{-\eta} c(r, \tau)^{\gamma-\eta} A_{EU}^{\gamma-1} (r + \rho\tau)^{-\gamma} \tag{A.1}$$

$$CO2_{RoW} = \Lambda^{\eta-1} \mu^{-\eta} c(r, \tau)^{\gamma-\eta} A_{EU}^{\gamma-1} r^{-\gamma} \tag{A.2}$$

We are now in a position to precisely define carbon EU leakage. We can measure the extend of carbon leakage by the change RoW emissions due to a increase of CO_2 pricing in the EU

$$\Delta^{Leak} CO2_{RoW} = \frac{\partial CO2_{RoW}}{\partial \tau} \Delta\tau$$

Looking at equation A.2 we see that leakage will occur if the cost increase from a change in τ has a negative effect on CO_2 emissions in RoW, which will be the case if $\gamma > \eta$. Put differently, leakage will not occur if EU and RoW capital are highly complementary ($\gamma \to 0$) or if the demand for a firm's output is highly elastic ($\eta \to \infty$). Equation A.2 also illustrates what it takes detect and quantify leakage in our firm level data: we would need controls for region specific shocks as well as firm specific shocks apart from changes in carbon prices or appropriate instruments. Alternatively, consider the equations A.1 and A.2 in terms of differences of log changes, i.e. approximately the difference in growth rates:

$$\Delta \ln CO2_{EU} - \Delta \ln CO2_{RoW} = (\gamma - 1)\,\Delta \ln A_{EU} - \gamma \Delta \ln (r + \rho\tau) - (\gamma - 1)\,\Delta \ln A_{RoW} + \gamma \Delta \ln r \tag{A.3}$$

Suppose a firm experience and increase in carbon prices from 0 to τ due to the ETS. We can re-write A.3 approximately as

$$\Delta \ln CO2_{EU} - \Delta \ln CO2_{RoW} \approx (\gamma - 1)\,\Delta \ln A_{EU} - (\gamma - 1)\,\Delta \ln A_{RoW} - \frac{\gamma}{r}\rho\tau$$

In other words if EU and RoW capital services are highly substitutable (γ is large), the carbon price increase τ is large relative to other capital cost factors r and other region specific productivity shocks have only confounding influence, then we should see that EU CO_2 emissions grow more slowly than RoW emissions.

Similarly, we can look at the EU share in emissions:

$$s_{EU} = \frac{A_{EU}^{\gamma-1}\,(r + \rho\tau)^{-\gamma}}{A_{ROW}^{\gamma-1} r^{-\gamma}}$$

Hence, provided that region specific productivity shocks are not confounding things, an increase in carbon prices τ should lead to a reduced EU share if there leakage is occurring.

B List of sectors judged at risk of carbon leakage

The following table lists all sectors that are coded at risk of carbon leakage (as detailed in Section 3). The number refers to the NACE Rev. 2 classification (Core Code, 4 Digits).

510 Mining of hard coal
610 Extraction of crude petroleum
710 Mining or iron ores
729 Mining of other non-ferrous metal ores
811 Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate
899 Other mining and quarrying n.e.c.
910 Support activities for petroleum and natural gas extraction
1081 Manufacture of sugar
1089 Manufacture of other food products n.e.c.
1101 Distilling, rectifying and blending of spirits
1102 Manufacture of wine from grape
1310 Preparation and spinning of textile fibre
1393 Manufacture of carpets and rugs
1413 Manufacture of other outerwear
1414 Manufacture of underwear
1520 Manufacture of footwear
1610 Sawmilling and planing of wood
1711 Manufacture of pulp
1712 Manufacture of paper and paperboard
1722 Manufacture of household and sanitary goods and of toilet requisites
1724 Manufacture of wallpaper
1729 Manufacture of other articles of paper and paperboard
1920 Manufacture of refined petroleum products
2012 Manufacture of dyes and pigments
2013 Manufacture of other inorganic basic chemicals
2014 Manufacture of other organic basic chemicals
2015 Manufacture of fertilisers and nitrogen compounds
2017 Manufacture of synthetic rubber in primary forms
2020 Manufacture of pesticides and other agrochemical products
2042 Manufacture of perfumes and toilet preparations
2059 Manufacture of other chemical products n.e.c.
2060 Manufacture of man-made fibres
2110 Manufacture of basic pharmaceutical products
2120 Manufacture of pharmaceutical preparations
2211 Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres
2219 Manufacture of other rubber products
2229 Manufacture of other plastic products
2311 Manufacture of flat glass
2319 Manufacture and processing of other glass, including technical glassware
2342 Manufacture of ceramic sanitary fixtures

2351 Manufacture of cement
2391 Production of abrasive products 2
2410 Manufacture of basic iron and steel and of ferro-alloys
2420 Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
2441 Precious metals production
2442 Aluminium production
2444 Copper production
2573 Manufacture of tools
2593 Manufacture of wire products, chain and springs
2599 Manufacture of other fabricated metal products n.e.c.
2611 Manufacture of electronic components
2612 Manufacture of loaded electronic boards
2620 Manufacture of computers and peripheral equipment
2630 Manufacture of communication equipment
2640 Manufacture of consumer electronics
2651 Manufacture of instruments and appliances for measuring, testing and navigation
2652 Manufacture of watches and clocks
2660 Manufacture of irradiation, electromedical and electrotherapeutic equipment
2670 Manufacture of optical instruments and photographic equipment
2711 Manufacture of electric motors, generators and transformers
2712 Manufacture of electricity distribution and control apparatus
2740 Manufacture of electric lighting equipment
2751 Manufacture of electric domestic appliances
2790 Manufacture of other electrical equipment
2811 Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
2813 Manufacture of other pumps and compressors
2814 Manufacture of other taps and valves
2815 Manufacture of bearings, gears, gearing and driving elements
2822 Manufacture of lifting and handling equipment
2823 Manufacture of office machinery and equipment (except computers and peripheral equipment)
2824 Manufacture of power-driven hand tools
2825 Manufacture of non-domestic cooling and ventilation equipment
2829 Manufacture of other generalpurpose machinery n.e.c.
2830 Manufacture of agricultural and forestry machinery
2891 Manufacture of machinery for metallurgy
2892 Manufacture of machinery for mining, quarrying and construction
2895 Manufacture of machinery for paper and paperboard production
2899 Manufacture of other specialpurpose machinery n.e.c.
3011 Building of ships and floating structures
3030 Manufacture of air and spacecraft and related machinery
3091 Manufacture of motorcycles
3099 Manufacture of other transport equipment n.e.c.
3101 Manufacture of office and shop furniture
3212 Manufacture of jewellery and related articles

3220 Manufacture of musical instruments
3230 Manufacture of sports goods
3240 Manufacture of games and toys
3250 Manufacture of medical and dental instruments and supplies
3299 Other manufacturing n.e.c.
5222 Service activities incidental to water transportation
5819 Other publishing activities
6209 Other information technology and computer service activities