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Searching for carbon leaks in multinational companies*

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Abstract

Does climate change policy cause companies to shift the location of production, thereby creating carbon leakage? We examine the impact of the European Union Emissions Trading System (EU ETS) on the geographical distribution of carbon emissions within multinational companies based on data from the Carbon Disclosure Project for the period 2007-2009. Our data includes regional emissions of 435 companies, of which 47 are subject to EU ETS regulation. We find no evidence that the EU ETS has induced a displacement of carbon emissions from Europe towards the rest of the world. Our results suggest that claims that the EU ETS would cause carbon leakage might have been exaggerated.

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1 Introduction

With the implementation of the European Union Emissions Trading System (EU ETS) and a range of other policies, mostly supporting the deployment of renewable energy technologies, the EU 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 for carbon and energy intensive industries. Indeed, in a free-trade world, increased carbon prices following adoption of unilateral climate policies may generate a pollution-haven effect in other countries or regions, whereby foreign countries specialise in the production of carbon-intensive products in which they have a newly acquired competitive advantage and which they can subsequently export back to "virtuous" countries. If the result of climate policy is a relocation of economic activity to less-regulated regions, then the policy is not only ineffective from a climate change point of view (as emissions are likely relocating with production, rather than reducing) but also costly from an economic point of view, by destroying jobs in environmentally-friendly countries. This issue has been referred to as "carbon leakage" and has attracted a lot of attention in the recent literature.

In this paper we explore this hypothesis using a unique sample of panel data on carbon emissions for 435 multinational companies. Multinational companies with operations across a wide range of jurisdictions might be particularly prone to react to regulation that imposes higher costs in some locations by shifting production to less regulated regions. Our data comes from the Carbon Disclosure Project, a non-profit data collection initiative established by parts of the investment community to collect climate change-relevant data at the level of individual businesses. Emissions for multinational businesses are broken down by country. Hence we can study whether multinationals reduce emissions in one location only to increase them elsewhere. Specifically we compare emissions in Europe with emissions occuring outside Europe within the same company between 2007 and 2009. On the basis of this data, we cannot find any evidence for 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 or trade-exposed.

This paper relates to the vast literature that seeks to estimate the impact of unilateral climate change policies on carbon leakage (see Dechezlepretre and Sato on energy prices and Dechezlepretre and Misato (policy brief) for recent reviews)[1]. This literature has so far mainly used ex-ante model simulation strategies, typically using Computable General Equilibrium (CGE) models and there are still few empirical contributions to this subject. These studies have estimated a wide range of leakage rates associated to different emission reduction targets under the Kyoto Protocol. Dröge (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 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 compensated by increased emissions in other regions, for example because production shifts to less-technologically advanced (and thus more carbon-intensive) regions. In the context of the EU ETS, partial equilibrium models have also been used, observing sectoral differences in carbon leakage rates due to differences in carbon intensity of production, abatement potential, transport costs, product differentiation and others parameters. Generally the steel sector, characterized by both high product differentiation and abatement potential, has been found to experience higher leakage rates (see Sato (2013)). Overall, these results are very sensitive to model assumption and are suggestive of a large uncertainty, highlighting the need for empirical studies to better identify the magnitude of the effect of climate change regulation on carbon leakage.

Recent work has made empirical contributions to this question. Aichele and Felbermayr (2012) and Aichele and Felbermayr (2011) analyse the impact of carbon emissions reduction commitments taken under the Kyoto Protocol on carbon leakege and find statistically significant and large effects. In the former paper, the authors find that the Kyoto commitment is associated with an increase in the ratio of imported embodied carbon emissions over domestic emissions by about 14%. Using a matching technique, the latter paper finds that exports by Kyoto countries are reduced by 13% to 14% following the signing of the protocol. Gerlagh and Mathys (2011) also provide empirical evidence supporting the carbon leakage effect. Using a panel of 14 high income countries over 28 years, they analyze the impact of energy abundance on country net exports and find that energy abundant countries have a higher level of energy embodied in

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

exports relative to imports.

A few recent studies have begun to investigate the impact of the EU ETS on carbon leakage. Martin et al. (2013b) review the ex-post empirical evidence of the impact of the EU ETS on carbon leakage. Although the studies outcomes differ across papers, there is overall no indication that the EU ETS had any strong negative effects on the economic performance of regulated firms and that it would have led to carbon leakage. Firm-level evidence from the French manufacturing sector shows no significant reduction of turnover during phases I or II (Wagner et al., 2013). A negative employment impact arises in a cross-country study, in particular in the non-metallic minerals industry (Abrell et al., 2011), suggesting that production might have shifted as a consequence of the EU ETS. In contrast, German manufacturing firms show no significant reduction in employment and turnover as a result of the EU ETS (Wagner et al., 2014). This is in line with sector-level evidence showing that firms' market power allows them to pass through the cost increases induced by carbon trading on to product prices (De Bruyn et al., 2008). Finally, Martin et al. (2013a) survey close to 800 manufacturing firms in six EU countries. Firms regulated under the EU ETS report a higher propensity to downsize their operations in response to future carbon pricing than non-EU ETS firms, but the overall effect is not large.

Our paper contributes to this literature by providing new evidence on the link between EU ETS regulation and carbon leakage. Thanks to the data collected by the Carbon Disclosure Project (CDP), we are able to track firm level CO_2 emissions for 6 years since 2005. Exploiting information on the country of origin of carbon emissions, we can directly assess the carbon leakage hypothesis by comparing the trend in CO_2 emissions of EU ETS regulated firms in European relative to non European countries.

The rest of the paper is structured as follows. The next section presents the different datasets used, in particular that obtained from CDP. Section 3 describes the method adopted for the data analysis and section 4 presents the results. Section 5 concludes.

2 Data and descriptive statistics

We construct an unbalanced panel of firms for the period 2005-2010 by combining different data sources. The data on annual firm level carbon emissions come from the Carbon Disclosure Project (CDP), an NGO acting on behalf of over 600 institutional investors which every year since 2003 asked listed companies to disclose information on emissions. More recently CDP also included non listed firms in its surveys. We obtain data on turnover, assets and sector of activity of these companies from ORBIS, one of the largest global financial firm level database maintained by Bureau van Dijk. Finally, we use the European Union Transaction Log to identify companies owning at least one installation regulated under the EU ETS [2].

As shown in Figure 1, the bulk of observations covers the 2007-2009 period. Our analysis therefore focuses on these three years of data[3]. The sample for these years is constituted of 435 companies, 47 of which are regulated under the EU ETS and 388 companies are not regulated.

Figure 1: Number of Observations over the Period 2005-2010.

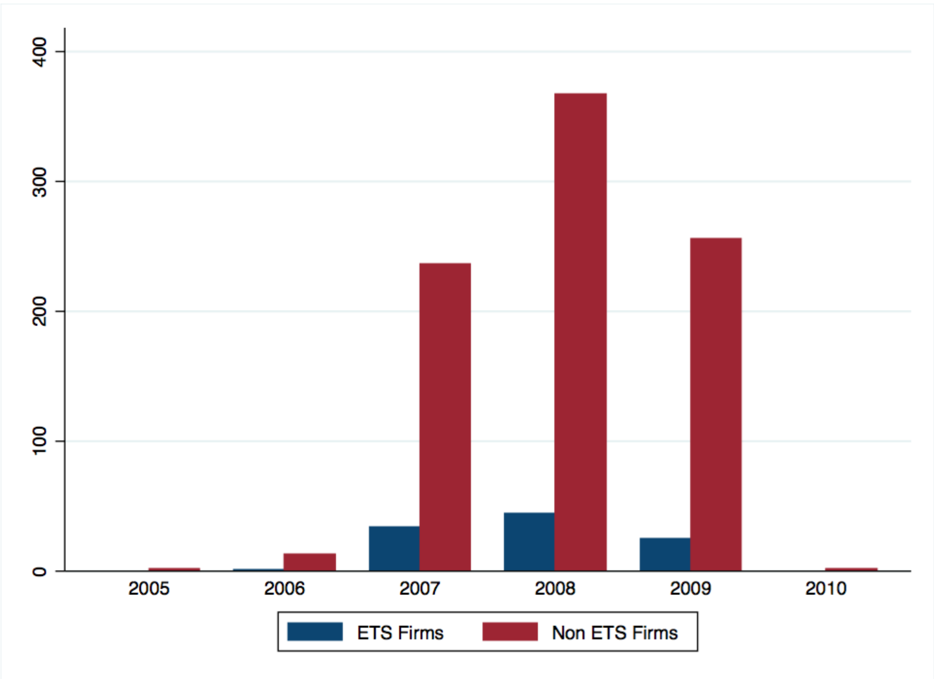


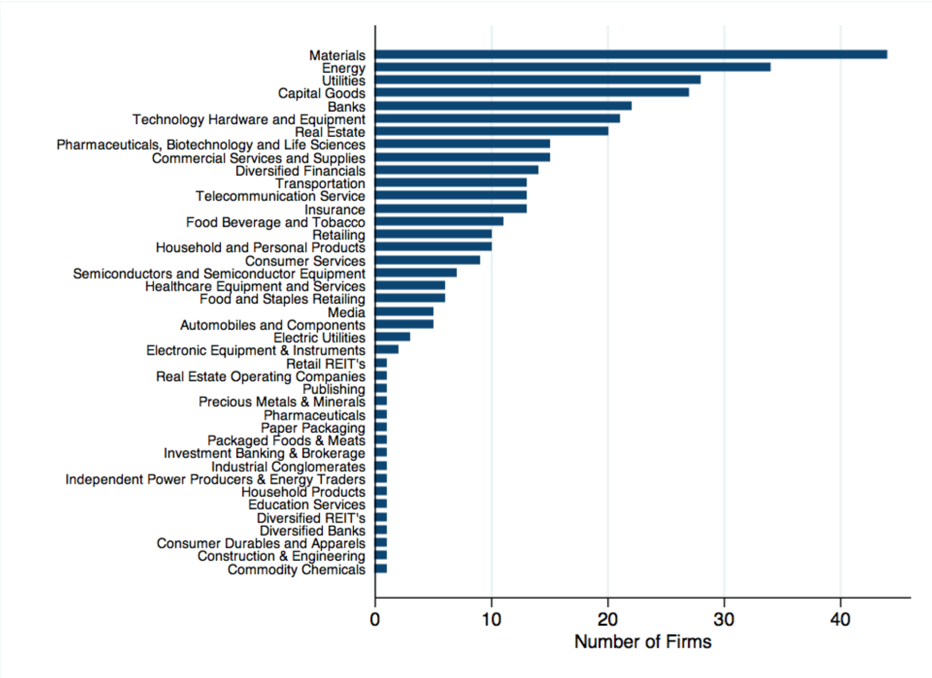
Figure 2 displays the sectoral distribution of the companies in our sample. The firms we observe

[2]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.

[3]In the Appendix we also report the results using data for the period 2005-2010.

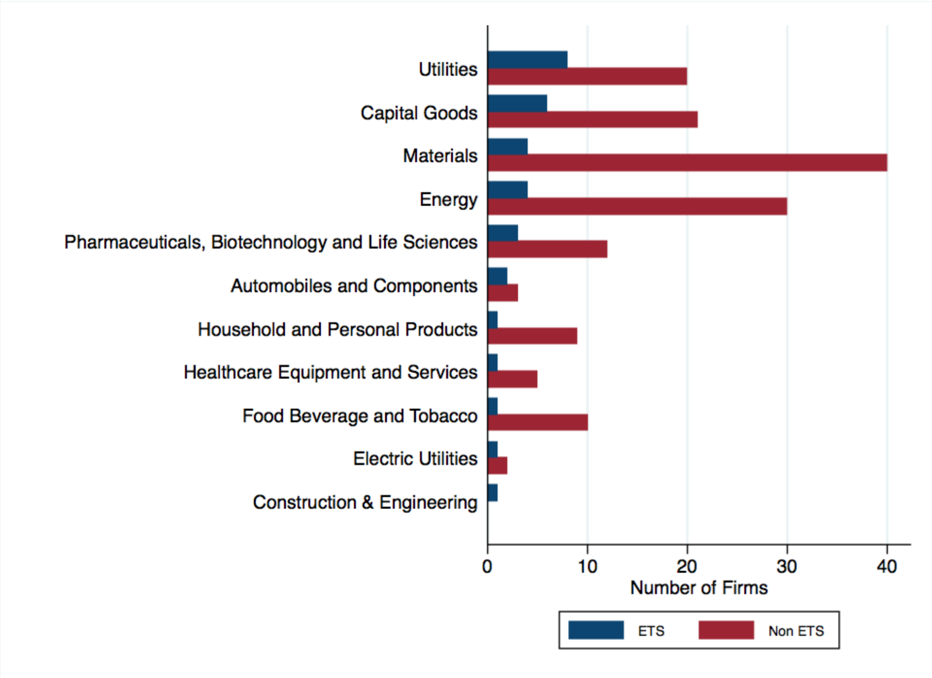
are the ones who voluntarily answer the CDP questionnaire so they represent a subset of listed firms. The majority of these companies comes from the materials, utilities and energy sectors. The sample also includes a large number of companies operating in the banking and financial sector.

Figure 2: Distribution of Companies Across Indutry Sectors



In Figure 3 we show the distribution of companies, focusing only on sectors where ETS firms operate. As expected the majority of ETS companies in the sample operate in the utility, capital goods and energy sectors.

Figure 3: Distribution of Companies across Industries where ETS Firms Operate



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. 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 of companies performing better relative to others from their sectors. 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 as 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. Our results are based on data that includes either type of firm.

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 ETS and non ETS firms.

3 Methods

There is a wide range of potential definitions and types of carbon leakage. The main contribution of this paper is that the data allows us for the first time to study leakage *within* firms. Leakage from the EU is understood here as the amount of CO_2 emissions re-located within multinational firms as a direct consequence of the introduction of climate policies within the EU. In Appendix A we introduce this more formally.

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 that goes along with positive emission growth in the RoW. 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 CO_2 emissions for firm i at time t. If carbon was systematically leaking from the EU within MNEs, we would expect $\Delta SHEU_{it}$ 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:

$$\Delta s_{it}^{EU} = \beta ETS_i + \gamma X_{it} + \varepsilon_{it} \tag{3}$$

where ETS_i is an indicator variable equal to 1 for firms regulated by the EU ETS and X_{it} is a vector of control variables.

Note that unfortunately the CDP data only covers years that have followed the introduction of the EU ETS. 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 would be hold for an extended period.

The main parameter of interest is β which is expected to be negative if the carbon leakage hypothesis is true. An important factor that might confound such an interpretation is the fact that ETS firms by definition have to be located in the EU (at some point) whereas this isn't the case for non-ETS firms. Hence any un-observed heterogeneity between EU and non-EU firms could affect the estimation of β. We address this by estimating equation **??** for a number of different subsets of the data. First, the sample is restricted to firms reporting non-zero emissions in both the EU and outside 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.

There are potentially further confounding factors distinguishing ETS and non-ETS firms. Most importantly, ETS firms are exclusively manufacturing firms or power plants.Therefore all the previous specifications are repeated restricting the sample to firms from those sectors. As an additional analysis, the regressions are run on a sub-sample of firms that belong to sectors deemed "at risk of carbon-leakage" by the EU Commission. Such sectors exceed certain thresholds in terms of carbon or trade intensity or both. Leakage effects would be expected to be particularly strong in such sectors.

4 Results

Table 1 reports the descriptive statistics for all 435 companies in the sample.

Table 1: Descriptive Statistics

Variables	Mean	Obs.	Source
CO_2 Emissions in Europe (Million Tonnes)	3.5302 (27.5027)	960	CDP
CO_2 Emissions outside Europe (Million Tonnes)	3.9017 (19.3696)	960	CDP
Share of CO_2 Emissions in Europe	0.3647 (0.4345)	960	CDP
Turnover (in USD Millions)	13.9819 (34.3459)	921	Orbis
Employees (in Thousands)	43.1655 (145.5539)	718	Orbis
Assets (in USD Millions)	60.9057 (244.2181)	911	Orbis

Standard Deviations in parenthesis.

In Table 2 a t-test comparing ETS and non-ETS companies is performed. Not surprisingly, ETS firms emit more both in European and non-European countries, and most of their production tends to be located in Europe. ETS firms are on average characterized by a higher turnover while they are similar to non-ETS firms in the number of employees and assets. The evidence changes when looking at manufacturing firms only and at firms at risk of carbon leakage. ETS firms in these two subgroups display significantly higher turnover and assets value than non-ETS firms. Also, ETS firms in the manufacturing sector are significantly larger in terms of the number of employees.

Table 2: ETS vs non-ETS Firms

Variables	Non ETS firms (mean) (1)	ETS firms (mean) (2)	Mean Difference (p-value) (3)
All Firms in Sample			
CO_2 Emissions in Europe (Million Tonnes)	1.2532 (10.1157)	25.4706 (66.1452)	-24.2173*** (0)
CO_2 Emissions outside Europe (Million Tonnes)	3.2574 (12.3362)	11.339 (37.3757)	-8.0816*** (0.002)
Share of CO_2 Emissions in Europe	0.3354 (0.4335)	0.6241 (0.3153)	-0.2887*** (0)
Turnover (in USD Millions)	12.1091 (28.2853)	29.9291 (55.852)	-17.82*** (0)
Employees (in Thousands)	38.0459 (131.78)	50.2680 (69.0772)	-12.2220 (0.5344)
Assets (in USD Millions)	62.8483 (254.2052)	41.013 (60.59)	21.8353 (0.5623)
Manufacturing Firms			
CO_2 Emissions in Europe (Million Tonnes)	0.6135 (3.6999)	4.2792 (11.1537)	-3.6657*** (0.0014)
CO_2 Emissions outside Europe (Million Tonnes)	4.3425 (15.4057)	12.8147 (44.1212)	-8.4721* (0.0646)
Share of CO_2 Emissions in Europe	0.2163 (0.3611)	0.4949 (0.3015)	-0.2785*** (0.0002)
Turnover (in USD Millions)	11.6972 (23.5698)	35.4178 (69.9865)	-23.7206*** (0.0011)
Employees (in Thousands)	29.8667 (47.4901)	59.2632 (75.8488)	-29.3965*** (0.0097)
Assets (in USD Millions)	12.6957 (21.5692)	42.2076 (69.0610)	-29.5119*** (0)
Manufacturing Firms "at Risk of Carbon Leakage"			
CO_2 Emissions in Europe (Million Tonnes)	0.3651 (2.7712)	5.0452 (13.6777)	-4.6801*** (0.001)
CO_2 Emissions outside Europe (Million Tonnes)	2.8113 (10.8562)	15.0897 (54.1517)	-12.2784** (0.0299)
Share of CO_2 Emissions in Europe	0.1853 (0.3302)	0.5014 (0.3000)	-0.3161*** (0.0002)
Turnover (in USD Millions)	10.5470 (18.4657)	13.4660 (12.458)	-2.9189 (0.5194)
Employees (in Thousands)	32.8719 (50.8713)	37.6708 (30.0025)	-4.7989 (0.6999)
Assets (in USD Millions)	12.0282 (19.1876)	24.6034 (37.6480)	-12.5751** (0.0303)

Standard Deviations in parenthesis in columns (1) and (2) and p-values in parenthesis in column (3). Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

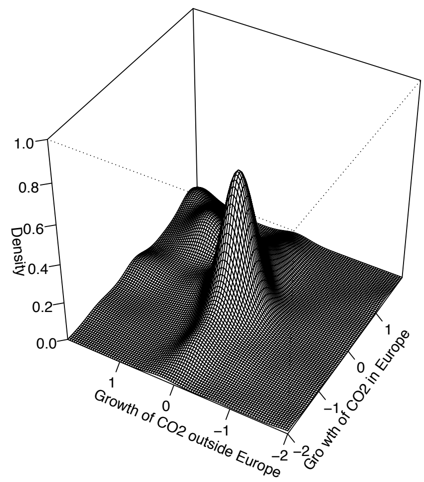
Figure 4 provides a graphical summary of our main findings relating to the growth of emissions. It reports the joint bi-variate distribution of the growth in CO_2 pollution in the EU versus the Rest of the World (RoW) at the level of firms.[4] Panel (a) shows the distribution for all firms with non-zero 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 don't change their carbon emission very much. There is also a notable mass of firms with positive emissions growth

[4]See equation 1.

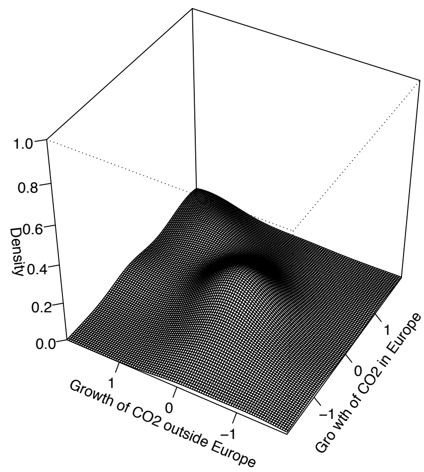
in both EU and RoW emissions. Panel (b) suggests that emissions growth is more heterogenous in ETS firms with a more uniform distribution. However, there is little evidence of such firms simultaneously reducing EU and increasing RoW emissions.Negative emission growth in the EU is rather associated with negative emission growth in the RoW as well. Hence, this indicates either genuine emissions reduction efforts globally or a decline of these sectors rather than leakage activity.

Figure 4: The joint distribution of changes in CO_2 emissions - EU vs RoW

(a) Firms with positive CO_2 in EU in base year



(b) Firms ETS firms



(c) Overlaid contour plots

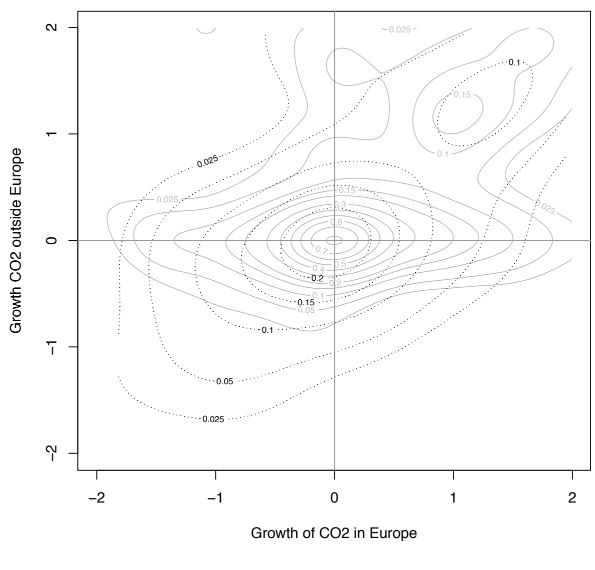
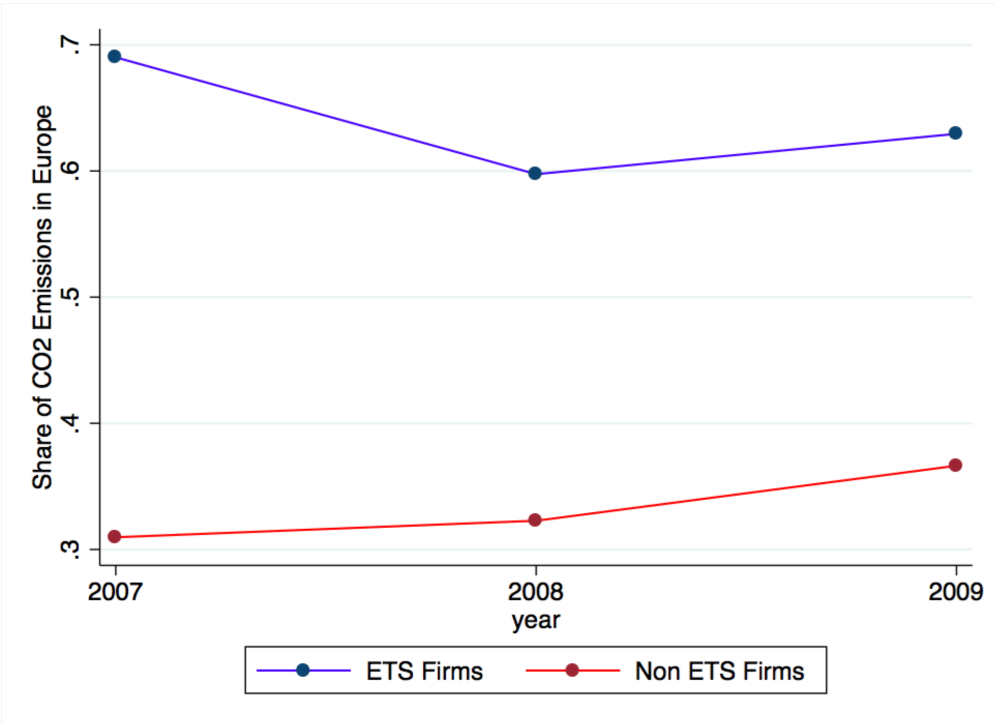


Figure 5 shows the share of CO_2 emissions in Europe over the period 2007-2009 for ETS and non-ETS firms respectively. It is consistent with the evidence presented in Table 2, showing that ETS-firms generate a larger share of emissions in Europe comparedto non-ETS firms. Between 2007 and 2008, ETS firms display a reduction in this measure compared to a slight increase experienced by non ETS companies. However on average the two groups follow a similar trend and the gap between them remains fairly stable over the period.

Figure 5: 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 main regressions results with the share of EU emissions as the dependent variable. Panel 1 reports regressions for all firms in our sample, Panel 2 reports on manufacturing firms and Panel 3 on firms in sectors considered at risk of carbon leakage according to the classification by the EU Commission (Emissions Trading Directive 2009/29/EC). As discussed above, the Commission determines if a sector is at risk by looking at carbon and trade intensity.

Moving through the columns of Table 3 we impose different restrictions regarding regional presence of firms. In column 2 we only include companies reporting positive emissions *both* in EU and RoW although not necessarily at the same time. Column three includes only observations from companies with positive EU emissions in the first period $(t-1)$. Finally, column 4 includes firms with positive EU emissions in the first period *and* non zero 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.[5] 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 that leakage effects are 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 positive and mostly insignificant throughout Table 3. Therefore we do not find evidence for a leakage effect, which would be characterized by a negative and statistically significant coefficient. What is more, it appears that rather than becoming negative - or at least less positive - the point estimates increase as we move to sub-samples potentially more at risk of leakage in Panel 3.

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

Table 3: Regressions of the share of emissions in EU

	(1)	(2)	(3)	(4)
Dependent Variable	Change in share of emissions from Europe			
	All Firms in Sample			
ETS	0.001	0.017	0.017	0.018
	(0.018)	(0.026)	(0.020)	(0.026)
Observations	525	197	291	182
R-squared	0.028	0.075	0.057	0.08
Number of Firms	435	172	246	159
Numb er ETS Firms	47	36	46	35
	Manufacturing Firms			
ETS	0.003	0.021	0.013	0.02
	(0.021)	(0.027)	(0.022)	(0.026)
Observations	218	104	120	93
R-squared	0.012	0.032	0.035	0.048
Number of Firms	183	90	102	81
Numb er ETS Firms	28	26	27	25
	Manufacturing Firms "at risk of Carbon Leakage"			
ETS	0.022	0.049*	0.032	0.037
	(0.023)	(0.028)	(0.023)	(0.023)
Observations	158	77	83	71
R-squared	0.039	0.164	0.092	0.178
Number of Firms	132	68	73	63
Numb er ETS Firms	18	17	17	16
Year Fixed Effects	Yes	Yes	Yes	Yes
Sectoral Fixed Effects	Yes	Yes	Yes	Yes

Notes: ETS is a dummy equal to 1 for the ETS regulated companies and zero otherwise. First column: All companies; Second column: companies reporting positive emissions BOTH in EU and non EU (non necessarily at the same time); Third column: companies reporting positive emission in EU in their first period; Fourth column: companies reporting positive emissions in EU in their first period and positive emission in non EU at some point in time. Clustered standard errors at the company level are in parenthesis. Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

In column 2 we even find that our point estimate is not only positive but also significant at the 10% level. What could be driving this result? 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 price shocks implied by the ETS. Secondly, we have to bear in mind that the EU 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". In future research we might be able to distinguish better between these two factors using the regression discontinuity strategy introduced in Martin et al. (2013a) and XXX Irrespective of the underlying reason it would seem that the result suggests that carbon leakage cannot be economically meaningful, be it because other factors are more important in determining the location of emissions or because anti-leakage policy measures are effective.

We have conducted a number of variations of the analysis reported in Table 3 for robustness purposes. Some of these are reported in Appendix B. For instance we re-compute the results in Table **??** while including additional control variables such as changes in capital stocks or turnover.

5 Conclusions

This paper uses a unique dataset that combines firm-level carbon emissions data with financial information to study the distribution of carbon emissions within 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 do not 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 2009. This might have been different for the most recent years of the EU ETS, or could change in the future if EU policy makers increased further the stringency of the policy. Our future research will explore these questions.

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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:

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

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

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

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

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

Equilibrium output is consequently determined by

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

Hence:

$$CO2_{EU} = \Lambda^{\eta-1}\mu^{-\eta}c\left(r, \tau\right)^{\gamma-\eta} A_{EU}^{\gamma-1}\left(r+\rho\tau\right)^{-\gamma} \tag{4}$$

$$CO2_{RoW} = \Lambda^{\eta-1}\mu^{-\eta}c\left(r, \tau\right)^{\gamma-\eta} A_{EU}^{\gamma-1} r^{-\gamma} \tag{5}$$

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 5 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 5 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 4 and 5 in terms of differences of log changes, i.e. approximately the difference in growth rates:

$$\Delta \ln CO2_{EU} - \Delta \ln CO2_{RoW} = (\gamma - 1)\, \Delta \ln A_{EU} - \gamma \Delta \ln (r + \rho\tau) - (\gamma - 1)\, \Delta \ln A_{RoW} + \gamma \Delta \ln r \tag{6}$$

Suppose a firm experience and increase in carbon prices from 0 to τ due to the ETS. We can re-write 6 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 Additional Specifications

Extended Period: 2005-2010

Table 4: Regressions of the share of emissions in EU (period: 2005-2010)

	(1)	(2)	(3)	(4)
Dependent Variable	Change in share of emissions from Europe			
	All Firms in Sample			
ETS	0.000	0.016	0.016	0.017
	(0.017)	(0.026)	(0.020)	(0.025)
Observations	543	202	298	187
R-squared	0.028	0.074	0.057	0.080
Number of Firms	437	172	247	159
Number ETS Firms	47	36	46	35
	Manufacturing Firms			
ETS	0.002	0.019	0.012	0.018
	(0.021)	(0.026)	(0.022)	(0.025)
Observations	227	106	123	95
R-squared	0.012	0.030	0.035	0.046
Number of Firms	184	90	103	81
Number ETS Firms	28	26	27	25
	Manufacturing Firms "at risk of Carbon Leakage"			
ETS	0.020	0.049*	0.030	0.037
	(0.022)	(0.029)	(0.023)	(0.024)
Observations	165	78	85	72
R-squared	0.037	0.164	0.090	0.178
Number of Firms	133	68	74	63
Number ETS Firms	18	17	17	16
Year Fixed Effects	Yes	Yes	Yes	Yes
Sectoral Fixed Effects	Yes	Yes	Yes	Yes

Notes: ETS is a dummy equal to 1 for the ETS regulated companies and zero otherwise. First column: All companies; Second column: companies reporting positive emissions BOTH in EU and non EU (non necessarily at the same time); Third column: companies reporting positive emission in EU in their first period; Fourth column: companies reporting positive emissions in EU in their first period and positive emission in non EU at some point in time. Clustered standard errors at the company level are in parenthesis. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Adding Control Variables

Table 5: Regressions of the share of emissions in EU

	(1)	(2)	(3)	(4)
Dependent Variable	Change in share of emissions from Europe			
	All Firms in Sample			
ETS	0.003	0.025	0.021	0.026
	(0.018)	(0.027)	(0.021)	(0.027)
Dassets	-0.019*	-0.036	-0.019	-0.041
	(0.011)	(0.029)	(0.016)	(0.027)
Dturnover	-0.015	-0.006	-0.023	-0.007
	(0.028)	(0.036)	(0.034)	(0.044)
Observations	495	184	279	170
R-squared	36	98	70	108
Number of Firms	411	160	235	148
Number ETS Firms	46	35	45	34
	Manufacturing Firms			
ETS	0.007	0.028	0.019	0.028
	(0.020)	(0.027)	(0.022)	(0.026)
Dassets	-0.088	-0.098	-0.097	-0.095
	(0.106)	(0.112)	(0.111)	(0.110)
Dturnover	0.022	0.013	0.017	0.012
	(0.013)	(0.034)	(0.023)	(0.041)
Observations	212	100	116	89
R-squared	0.021	0.049	0.051	0.071
Number of Firms	183	90	102	81
Number ETS Firms	28	26	27	25
	Manufacturing Firms "at risk of Carbon Leakage"			
ETS	0.026	0.062**	0.039	0.050*
	(0.026)	(0.031)	(0.027)	(0.025)
Dassets	-0.023	-0.041	-0.029	-0.031
	(0.031)	(0.034)	(0.034)	(0.029)
Dtunover	0.084	0.037	0.092	0.017
	(0.079)	(0.117)	(0.111)	(0.127)
Observations	153	74	80	68
R-squared	0.045	0.222	0.110	0.253
Number of Firms	132	68	73	63
Number ETS Firms	18	17	17	16
Year Fixed Effects	Yes	Yes	Yes	Yes
Sectoral Fixed Effects	Yes	Yes	Yes	Yes

Notes: ETS is a dummy equal to 1 for the ETS regulated companies and zero otherwise. First column: All companies; Second column: companies reporting positive emissions BOTH in EU and non EU (non necessarily at the same time); Third column: companies reporting positive emission in EU in their first period; Fourth column: companies reporting positive emissions in EU in their first period and positive emission in non EU at some point in time. Clustered standard errors at the company level are in parenthesis. Significance levels: *** p<0.01, ** p<0.05, * p<0.1

Changing Dependent Variable: time varying intervals relative to 2007 (t-2007) instead of (t-t-1)

Table 6: Regressions of the share of emissions in EU

	(1)	(2)	(3)	(4)
Dependent Variable	Change in share of emissions from Europe			
	All Firms in Sample			
ETS	0.000	0.010	0.013	0.013
	(0.013)	(0.021)	(0.016)	(0.021)
Observations	628	233	337	209
R-squared	0.034	0.088	0.069	0.106
Number of Firms	435	172	246	159
Number ETS Firms	47	36	46	35
	Manufacturing Firms			
ETS	0.000	0.009	0.008	0.011
	(0.016)	(0.021)	(0.018)	(0.022)
Observations	255	134	144	116
R-squared	0.020	0.039	0.056	0.073
Number of Firms	183	90	102	81
Number ETS Firms	28	26	27	25
	Manufacturing Firms "at risk of Carbon Leakage"			
ETS	0.018	0.031	0.029	0.027
	(0.018)	(0.024)	(0.021)	(0.022)
Observations	186	95	96	84
R-squared	0.032	0.086	0.091	0.119
Number of Firms	132	68	73	63
Number ETS Firms	18	17	17	16
Year Fixed Effects	Yes	Yes	Yes	Yes
Sectoral Fixed Effects	Yes	Yes	Yes	Yes

Notes: ETS is a dummy equal to 1 for the ETS regulated companies and zero otherwise. First column: All companies; Second column: companies reporting positive emissions BOTH in EU and non EU (non necessarily at the same time); Third column: companies reporting positive emission in EU in their first period; Fourth column: companies reporting positive emissions in EU in their first period and positive emission in non EU at some point in time. Clustered standard errors at the company level are in parenthesis. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.