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Multinational Corporations and the EU Emissions Trading System: Asset Erosion and Creeping Deindustrialization?

Abstract

This study investigates the causal effect of the EU Emissions Trading System (EU ETS) on firms' holdings of fixed assets as an early indicator of industrial relocation, exploiting installation level inclusion criteria of the regulation. To single out companies with particularly low relocation costs, global multinational enterprises (MNEs), we identify ownership structures for the full sample of EU ETS-firms. Matched difference-in-differences estimates provide robust evidence that contradicts the idea of an erosion of European asset bases. Baseline results indicate that the EU ETS led on average to an increase of treated firms' asset bases of 11,1%. However, for a particular subgroup of MNEs, this increase is a mere 1.3%. For these companies, the EU ETS may have induced a shift in investment priorities. While the positive overall effect is very robust, the differential effect for the subgroup cannot be extended to all samples.

JEL Classification: F23, H23, Q54, Q58, C21

Keywords: EU ETS; cap-and-trade; carbon leakage; multinational corporation

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1. Introduction

The EU Emissions Trading System (EU ETS) is the world's largest carbon market and the EU's flagship tool to combat climate change. The launch of this transboundary carbon trading system marked a severe tightening of environmental regulation in a unilateral way: Starting in the year 2005, EU firms in energy and manufacturing industries faced a strict cap on their total amount of greenhouse gas emissions while the perspective for a widespread implementation of comparable regulations in other regions of the world was uncertain. Even though a number of regional and experimental carbon trading programs were started subsequently to the EU ETS, these regionally or temporally confined initiatives did not alter the unilateral character of the EU ETS in comparison to the substantially lower stringency of climate change policies outside of Europe. Against this backdrop, concerns about potentially negative competitiveness impacts on regulated businesses under the EU ETS were voiced from its inception and have not died out since.

The concern that unilateral environmental regulations might impose significant costs, divert resources from productive activities and ultimately put the international competitiveness of regulated firms at risk is widespread among economists, policymakers and industry representatives. In case of a persistent international asymmetry in the stringency of environmental regulation, the pollution haven hypothesis is that affected businesses may move production capacity to countries that impose a lighter regulatory burden. In the context of climate change policies, such a shift creates "carbon leakage", since the emissions would move together with the relocated production. In this scenario, the unilateral environmental policy backfires economically and ecologically, combining a loss of economic activity in industrial sectors with, at best, environmental ineffectiveness, or worse, an outright negative effect if production outside of the regulated area is carried out in a more carbon intensive way. Such a process would manifest itself in the form of an erosion of the regulated firms' asset bases in Europe.

This study is the first comprehensive analysis of the EU ETS that investigates industrial relocation in the form of a possible erosion of European assets by assessing the risk where it is most likely to materialize first, i.e. within subgroups of multinational enterprises that already encompass firms within and outside of the regulated area. Using an extensive firm-level accounting database, we are not only able to match 96% of 8.578 EU ETS-firms (8.218) with respective financial accounts and thereby cover 14.507 out of 15.043 installations regulated by the EU ETS (as of March 2014). Additionally, the global reach of our firm database provides the basis for the identification of five types of business group structures, reaching from single firms over variants of multi-firm business groups within the EU ETS (i.e. with establishments in one or several EU ETS-countries) to two different subgroups of global multinational enterprises.

This differentiated identification of corporate structures across the universe of firms subjected to the EU ETS is essential to address our research question. Due to their specific organizational structure, only global multinational enterprises with existing firms inside and outside of the regulated area may possess the opportunity of a gradual reaction at rather low relocation costs. If relocation takes place on an important scale via this channel, we should observe asset erosion for these firms or at least no substantial increases in the asset base. We argue that the cost barrier for a relocation of economic activity should be lowest within global business groups that comprise, regarded from the viewpoint of a specific firm subject to the EU ETS, at least one firm that operates in the same sub-sector but is located outside of the regulated area. In principle, this would allow for a simple shift of production between already existing firms. We therefore designate the firm in a business group as *global MNE with functional link*. In contrast, we denote a treated firm as belonging to a *global MNE without functional link* if the business group is indeed spread across regulated and unregulated countries but lacks ownership of a sectoral sibling outside of the EU ETS.

We set up our research design with the explicit aim to detect indications for processes of asset erosion and creeping deindustrialization by focusing on, as our central variable of interest, the tangible fixed assets as recorded in the annual accounts. It states the value of production capacities such as plants, machinery and equipment. A rising year-on-year value reflects investment that exceeds depreciation whereas a declining value points towards either a low level of investment (below annual depreciation) or outright divestment, i.e. to the closure or sale of facilities. At the same time, this outcome variable embodies a forward-looking quality. Due to the inherent link between the evolution of the value of tangible assets and the underlying investment activity of the respective firm, which is by definition forward looking, the analysis also reflects the regulatory pressure that treated firms expect the EU ETS to exert in the long run.

We apply a matched difference-in-differences approach that exploits the installation-level inclusion criteria of the EU ETS to compare firms that are very similar in a number of important characteristics but, due to the application of specific thresholds, fall under different regulatory regimes since the start of the EU ETS in 2005. This study design enables us to control for confounding factors that affect regulated and unregulated firms and to take account of firm-level heterogeneity. By means of this quasi-experimental approach, we assess the causal impact of the EU ETS on the fixed asset bases of treated firms. To investigate in particular whether firms that belong to global multinational enterprises react differently than firms without this structure-based option, we interact the treatment effect with an indicator variable that denotes for every firm to which kind of business group structure it belongs.

Highly significant baseline results for the whole treatment period from 2005 through 2012 indicate that the EU ETS led to an overall increase of treated firms' fixed asset bases of 11,1%. However, we find a markedly different reaction for those firms that belong to a global MNE *without functional link*. Treated firms that belong to this category of MNEs display a highly significant interaction effect. It implies an increase in tangible fixed assets of only 1.3%, i.e. 9.8% below the remainder of the treatment group and appears to be driven by manufacturing firms. Assessing the first two trading phases reveals that both effects, the overall treatment effect and the differential effect for firms that belong to global MNEs without functional link, are more pronounced in phase II. In contrast, for EU ETS-firms that are part of a global MNE *with functional link*, the coefficient estimates for the interaction effect are of irrelevant magnitude and statistically not significant. Our findings indicate that while the EU ETS has clearly not led to an erosion of European asset bases, some MNEs obviously committed comparatively less investment in response to the regulation. This result suggests a shift of investment priorities for this particular subgroup.

In several extensions of the analysis, the overall treatment effect proves to be highly robust. However, the interaction effect that indicates a differential behavior of those EU ETS-firms that belong to global MNEs without functional link turns insignificant when we try to enhance the external validity of our findings by broadening the samples used. In contrast, both effects are confirmed if we put more weight on internal validity by tightening the sample restrictions.

Related Literature Our study relates to three different strands of research. Firstly, we contribute to the literature on the pollution haven hypothesis (see Brunnermeier and Levinson 2004; Copeland and Taylor 2004; and Erdogan 2013 for reviews). With respect to climate policy, carbon price differentials across regions could drive production of energy-intensive goods to "carbon havens", thereby creating "carbon leakage". Ex ante simulations that try to gauge the size of leakage rates with Computable General Equilibrium (CGE) models conclude that the leakage rate of a unilateral carbon tax (or ETS) is in the range of 5-30% (Böhringer et al. 2012; Zhang 2012). However, the few ex-post studies for the EU ETS have so far not revealed any substantial leakage effect, neither via sectoral trade flows (e.g. Naegele and Zaklan 2016), nor through a rise in Foreign Direct Investment, analyzed for Italian MNEs by Borghesi et al. (2016) and for German MNEs by Koch and Basse Mama (2016). The study that most closely shares our conceptual emphasis on potential intra-firm shifts of emissions is Dechezleprêtre et al. (2015). We contribute to this literature by providing a comprehensive analysis that draws on 96% of the firms subject to the EU ETS and focuses on European asset bases rather than outward effects.

Secondly, this study is related to the growing empirical literature that evaluates the impact of the EU ETS on various dimensions of firm competitiveness (Anger and Oberndorfer 2008; Abrell et al. 2011; Bushnell et al. 2013; Chan et al. 2013; Commins et al. 2011; Petrick and Wagner 2014; Wagner et al. 2014; see the review by Martin et al. 2016). A broad set of indicators is used to analyze effects on economic performance, such as profits, revenues, output, and employment. Early contributions often lacked a convincing identification strategy, falling short of fulfilling the exigencies for credible estimates of causal effects as delineated in, e.g., Imbens and Wooldridge (2009) or Greenstone and Gayer (2009). Calel and Dechezleprêtre (2016) were the first to introduce the idea of exploiting the installation-level inclusion criteria of the EU-ETS to compare firms that are very similar but differ in their treatment status. In the context of competitiveness, recent studies built on this concept and applied quasi-experimental techniques to obtain more credible causal effects based on country specific administrative data (Petrick and Wagner 2014 and Wagner et al. 2014) or commercial databases (Marin et al. 2015).

Finally, our analysis of corporate structures based on the bottom-up tracing of majority ownership links relates to similar endeavors by Jaraite et al. (2013), Vitali et al. (2011), Altomonte and Rungi (2013) and UNCTAD (2016, chap. IV). Given that multinational enterprises are the dominant force in the economic sectors subject to the EU ETS, the explicit consideration of these structural aspects is clearly warranted. Studies from empirical management science like Fisch and Zschoche (2011) show that multinationality can, besides other benefits, also provide operational flexibility to firms that might be faced with adverse cost shocks in one or several locations, an argument raised on theoretical grounds already by de Meza and van der Ploeg (1987). This benefit was later framed as the "option value of a multinational network" by Kogut and Kulatilaka (1994). The differential results that we obtain for treated firms that belong to a special variant of global MNEs suggest that the explicit analysis of ownership complexity is an important issue in evaluations of environmental policy instruments like the EU ETS.

The remainder of the paper is organized as follows. Section 2 introduces the institutional background for our analysis with respect to the EU ETS. Section 3 provides a description of the data as well as descriptive evidence for the high relevance of global MNEs within the EU ETS. Section 4 outlines our empirical strategy. In section 5, we present the results of our analysis. Section 6 discusses the results and concludes.

2. Emissions trading and industrial relocation

Launched in 2005, the EU ETS is today the European Union's flagship policy to comply with European and international commitments that seek to mitigate climate change. It is the largest emissions trading system worldwide and imposes a cap on the total amount of greenhouse gas emissions in 31 European countries from approximately 12.000 heavy energy-using sources. As of 2016, this system covers around 45% of all greenhouse gas emissions of the 28 EU member states, plus Iceland, Lichtenstein and Norway. The main organizing principle of the EU ETS is "cap-and-trade": At the start of a trading period a cap is set on the total amount of emissions. Emissions allowances ("EU Allowances" - EUAs) are then allocated - either for free or via auctioning - to regulated entities. Each allowance corresponds to one ton of CO2-equivalent. At the end of each year, firms have to report their emissions and surrender allowances equal to the number of verified emissions. Non-compliance with this results in substantive penalties.[1] Within a given period, market participants can trade their allowances freely. This, combined with the induced scarcity, establishes a price for the ton of emissions. The total amount of allowances per period, i.e. the cap, is reduced from period to period, thus causing total emissions to decrease over time. The first trading period of the EU ETS (2005-2007), known as the pilot phase, was characterized by almost entirely free allocation of emission allowances and a cap that was highly decentralized and set on the member state level.[2] Banking of allowances was not permitted, thus making the cap detached from future periods.[3] Phase II (2008-2012) represented the first commitment period under the Kyoto protocol and established an EU-wide cap with a single Union Registry covering all regulated installations. While free allocation was still the default mode of allowance allocation (around 90%), banking allowances for future periods was now possible. The scope of the EU ETS expanded in terms of countries, sectors and regulated emissions.[4]

[1] In the first trading period (2005-2007), the fine was 40€ per ton CO2-equivalent. In the second period (2008-2012), the fine was 100€.

[2] For a more comprehensive review of the EU ETS design features, see Martin et al. (2016).

[3] Source: https://ec.europa.eu/clima/policies/ets/pre2013_en.

[4] Three countries (Iceland, Lichtenstein and Norway) joined the EU ETS in phase II. In terms of regulated firms, the aviation sector was brought into the scheme. Since its regulatory conditions are very different from other sectors, we do not cover it in our analysis. In 2013, (phase III) Croatia

Phase II also saw a decrease in the overall cap (6.5% lower than in 2005). However, phase II coincided with the 2008 financial crisis that led to a global economic depression. As a consequence, economic activity and associated emissions were substantially lower during phase II than originally expected. At the end of phase II, the market had accumulated a large surplus of allowances and credits from international abatement projects. The average allowance price during phases I and II was slightly above 14 Euros. However, at the end of each period, the price per permit dropped considerably below 10 Euros.[5] For the third phase of the EU ETS (2013-2020), auctioning is targeted to becoming the default mode of allowance allocation.

Possibly adverse impacts of the EU ETS on the economic performance of regulated firms have been intensely discussed since the early inceptions of the EU ETS. Imposing a carbon price can increase the production costs of regulated firms through two different channels (Ellerman et al., 2016). First, firms either have to implement costly abatement measures or purchase permits on the market. Costs for firms increase further if EUAs are allocated via auctioning, although this has not been the default allocation mode in phases I and II. Even if the initial permit endowment for each phase is mostly based on free allocation, the obligation to hold permits per se creates an opportunity cost.[6] Second, if the power sector passes down such cost increases to consumers, this leads to further indirect costs of the EU ETS for manufacturing companies regardless of whether or not they are part of the scheme. For manufacturing companies competing in international markets it may not be possible to pass down regulatory costs to their consumers without losing market shares. This may not only lead to a short term decrease in production and employment levels, but could also engender a relocation of economic activity of firms towards areas with less regulation.

joined the scheme.

[5] Calculations based on ICE Futures Europe EU Allowance data. In December 2012, the average EUA future price was 7.2 Euros. In neither of the two phases did the price drop to zero.

[6] A firm can obtain a benefit from abating an additional ton of CO2-equivalent if the marginal benefit gained from selling the permit is bigger than the marginal abatement costs.

3. Business groups in the EU ETS

The threat of industrial relocation has been a major concern for EU and national policy makers and is frequently used by industry groups to obtain concessions. Such a process may not only cost jobs and economic activity in Europe, but undermine the effectiveness of the EU ETS as a tool to combat climate change as emissions relocate along with production capacities. In response, free allocation rather than auctioning became an important design feature for the first two regulatory phases. Also, in 2010, the EU commission introduced a "carbon leakage list" that comprises all manufacturing subsectors deemed to be at a very high risk of shifting activities in response to the EU ETS.[7] For regulatory phase III, companies on this list receive a higher share of free allowances.

Firms subject to the EU ETS may, based on their expectations of future benefits and costs, optimize their decisions for the short and long term in terms of either committing to the policy (i.e. investing into their asset base, e.g. by employing abatement technolocy) or conducting a full or partial relocation (i.e. divesting the asset base). However, in the medium term, a total relocation of firms subject to the EU ETS, even for those at high risk of carbon leakage, seems unlikely. Firstly, the EU ETS may create benefits for the regulated firms. Aside from the still high levels of free allocation and the windfall profits associated with it, firms may obtain an advantage over international competitors in the long run if cleaner technologies turn out to be more competitive.[8] Also, whereas the design of carbon policies in most parts of the world is still uncertain, the EU ETS provides regulatory stability and a clear path for emissions reduction.

Given the policy context at hand, we would not expect companies to divest rapidly in response to the EU ETS. Instead, we analyze industrial relocation as a process that

[7] According to Directive 2003/87/EC, referenced in Commission Decision 2014/746/EU a sector is deemed and risk if certain thresholds are surpassed, e.g. their high exposure to international competition and/or the energy intensity of their production. However, the optimality of the inclusion criteria has been disputed (Martin et al., 2015)

[8] A long-lasting discussion of the potential positive impacts of environmental regulation on affected firms' competitiveness was started by Porter and van der Linde, Claas (1995), the results of which have been summarized in Ambec et al. (2013). They conclude that "the evidence for the "weak" version of the Porter Hypothesis (that stricter environmental regulation leads to more innovation) is fairly clear and well established. However, the empirical evidence on the strong version of the Porter Hypothesis (that stricter regulation enhances business performance) is mixed.

has been described as "creeping deindustrialization". The relocation would not manifest itself in large and sudden shifts, but rather take place through a slow restructuring of assets over time.[9] For this purpose, our study attempts to identify the causal impact of the EU Emissions Trading System on the asset bases of treated firms between 2005 and 2012. In a second step, we narrow down our analyis to investitage if companies that are part of a global multinational network react differently to the regulation. The empirical and theoretical literature on multinational firm structure has long argued that these companies have particularly low relocation costs and thus the ability to adapt flexibly to cost shocks by using their international networks to shift resources (Fisch and Zschoche 2011). Uncertainty of future operating costs, as de Meza and van der Ploeg (1987) argue, may lead companies to dedicate future investments to locations with more favorable conditions, especially in the case of long term and irreversible capital investment. For these networks, this may serve as a hedging strategy to absorb future cost shocks more easily (Kogut and Kulatilaka 1994). These shifts in investment patterns into already existing asset bases can take place gradually, allowing the network to adapt over time to changes in expectations of costs and benefits related to carbon policy. This is why this potential channel of relocation may be very important in the context of the EU ETS.

To investigate the role of multinational business groups in the EU ETS, we combine data from several sources. Our primary datasource is the ORBIS database maintained by the commercial data provider Bureau van Dijk (BvD). ORBIS is a global firm-level database that harmonizes financial data into a global standard format, allowing for cross-country comparisons. The financial data we use was extracted by Bureau van Dijk in the last week of November 2015. Included are all firms above a turnover of one million Euro, total assets of 2 million Euro or a total number of 15 employees in 2015, which amounts to a sample of around 12.5 million firms.[10] We then reduce the data to the period from 2002-2012 and drop all firms that were incorporated after 2004. Finally, we limit the data to countries and sectors that are covered by the EU ETS. The resulting dataset consists of an unbalanced panel of 1.7 million firms and 14.5 million observations. Several steps have

[9] Cowie and Heathcott (2003) illustrates the changes in the US manufacturing sector in the 1980s.
[10] To ensure a high data quality we use unconsolidated financial information from local registry filings.

to be taken to correct for potential errors and changes in the database. The financial data does not indicate separately whether any special events (such as mergers and acquisitions) happened to a firm in any given year. We identify anomalies in the data and exclude firms with implausible values (such as negative total assets). To account for anomalies, we transform all variables of interest into growth rates, then calculate the yearly distribution per variable and flag the 0.1% largest jumps per year per variable. A firm with one such event is then discarded completely. This method eliminates a wide range of data errors as well as firms that were subject to very special transformations (which we assume not to have anything to do with the EU ETS), but does not eliminate firms that are merely very large or growing very fast. However, we also encode size outliers as being part of the 1% largest firms in a given year.[11] ORBIS is to date the only data source that contains information allowing to identify and track ownership relationships across time and space with global reach. One challenge for the empirical researcher here is the fact that ORBIS is updated weekly. Changes of firms' Bureau van Dijk identification number (bvdid) are thus frequent. We were able to download data for all changes made until November 2015 - a total of more than 45 million unique changes to bvdids. We use this data to update all bvdids and correct for all changes.

To construct the ownership structures, we first extract ownership data for all firms in ORBIS above our already defined threshold for small companies. We enhance this sample of 12.5 million firms with the first-level top shareholders of these firms in any period as well as their current subsidiaries, regardless of any other criteria. To close gaps in our chains of ownership, we add all current subsidiaries as of August 2015 to this sample. These firms were either smaller than our initial selection or empty in terms of their financial information. Our selection of firms for which we extract ownership information then adds up to a total number of 14.4 million firms. For these firms we then manually downloaded the available ownership data in batches of 25.000 firms for each year from 2002-2014.[12] Of these firms only 3.2 million firms are actually owned by

[11] Applying the jump outlier correction affects 5.35% of observations and 5.25% of firms. Applying the size outlier category afterwards affects 2.21% of observations and 2.24% of firms.

[12] All of our exports took place between January and August 2015 and were verified against a unified backbone identification dataset and using identical export profiles. We also systematically corrected

a top shareholder in at least one period between 2002 and 2012. Only a tiny share of firms has constant data, i.e. no changes in ownership structure in that period. We then use this information to construct chains of ownership. Following a similar methodology as Jaraite et al. (2013), we link firms with more than 50.01% ownership shares until we reach the top of the chain of control. We are thus able to identify global ultimate owners, but can also fully map business group structures for our entire dataset. Unlike previous approaches, we can repeat this process yearly, and identify structural changes over time.

Data on the EU ETS is provided by the European Union Transaction Log (EUTL). This registry contains information on all regulated plants.[13] We enhance the dataset with plant-level information on emissions, location, sector-specific risk of carbon leakage according to the definition of the EU commission and a reference dataset for GUOs via the combination of installation identifier and country ISO code.[14] In order to identify all companies within ORBIS that are subject to the EU ETS, we match the information contained in the EUTL on a company level with ORBIS by employing national identification numbers contained in both datasets. Systematic errors in the EUTL are identified and corrected to make national identifiers compatible with the country specific formats in ORBIS. In a few cases, companies could not be tracked via their national identifier and were matched via their name. We successfully match 8.218 out of all 8.578 companies (96%) that hold installations regulated by the EU ETS as of March 2014. This corresponds to 14.507 out of a total of 15.043 plants (96%). The remainder of 360 companies (536 plants) could not be matched: In some cases, companies can simply not be found in ORBIS or their bvdids are not available. In others, the exact firm cannot be identified due to incomplete or inconclusive information in ORBIS. Many of the not-matched entries are hospitals, governmental agencies or universities. In order to ensure correct matches, we

for remaining human errors in this process and verified its integrity to the best of our ability.

[13] The document "List of Stationary Installations in the Union Registry" contains all plants under the EU ETS as of February 27, 2014. It can be retrieved from http://ec.europa.eu/clima/policies/ets/registry/documentation_en.htm.

[14] The document "Classification of installations in the EUTL Registry based on the NACE 4 statistical classification" contains plant-level information on allocated, surrendered and verified emissions per year. It is available at http://ec.europa.eu/clima/policies/ets/cap/leakage/studies_en.htm. For consistency checks we also use the dataset provided by Jaraite et al. (2013). It links EU ETS plants to their respective GUOs for the period 2005-2007 and is available at http://fsr.eui.eu/EnergyandClimate/Climate/EUTLTransactionData.aspx.

run several consistency tests by comparing the companies' contact information between EUTL and ORBIS. For 98.2 % of the matched sample, the information between both sources is consistent indicating a very high matching quality.[15] The matched EU ETS firms are then reduced to those active in phase I or II of the EU ETS, using the emission data from the EUTL as an indicator of activity. Based on the matched bvdid we identify the remaining 7.279 firms in our ORBIS sample of 1.7 million firms. Note that we rely on information from 2014 to identify the firms regulated by the EU ETS in phases I and II. We then identify ownership structures from the bottum up and categorize five different types of business group structures.

Our analysis always remains on the level of the individual firm. *Independent firms* are all firms without ownership data.[16] We denote a firm as part of a *National business group* if all firms in the network are located in the same country. *MNEs operating within the EU ETS area* are international business groups, but fully covered by the EU ETS. *Global MNEs without functional link* include at least one firm based in a country that is not regulated by the EU ETS. *Global MNEs with functional link* include at least one firm that is outside of the EU ETS area and operates in the same NACE 2-digit sector. This differentiated identification of corporate structures is essential to address our research question. We argue that the cost barrier for a relocation of economic activity should be lowest within global business groups that comprise, regarded from the viewpoint of a specific firm subject to the EU ETS, at least one firm that is located outside of the regulated area and even more so if this firm represents a *functional link*, i.e. is operating in the same sub-sector. In the latter case, this would allow for a simple shift of production between already existing firms.

[15] For 1.8% of the sample, part of the information differs. This is mostly related to changes in company names or mergers and acquisitions.

[16] Consequently, even firms placed on top of corporate hierarchies are not considered to be independent, but firms which are part of a corporate network but do not report ownership information are.

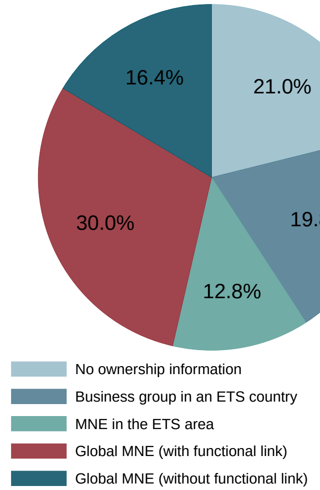


Figure 1: Firms by firm type in manufacturing, 2012

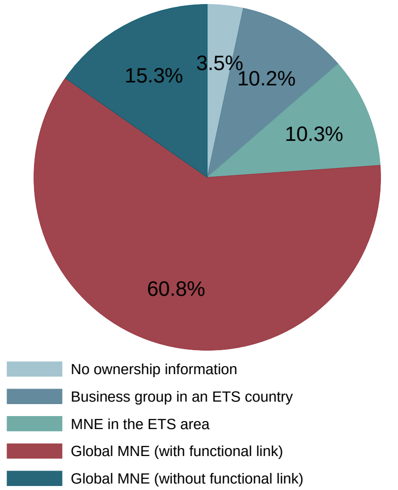


Figure 2: Verified emissions by firm type in manufacturing, 2012

We now explore the importance of these firms pertaining to global business groups within the EU ETS. We focus on the manufacturing sector, which is, unlike the energy sector, often deemed at risk of industrial relocation. Figure 1 splits the sum of firms by firm type while Figure 2 does the same for the verified emissions in 2012. Only around a fifth (21%) of all firms within the EU ETS were actually independent and accounted for a mere 3.5% of total emissions.

Firms that belong to a *Global MNE* comprised 42.8% of all firms and, more remarkably, accounted for the bulk (76.1%) of all verified emissions. For all business groups, we then aggregated emissions for the firms at the top of their respective corporate hierarchies, the global ultimate owners. In total, the 10 largest business groups in terms of emissions accounted for over 30% of all verified emissions from 2005-2012. More than half of all emissions can be attributed to the top 50 business groups, connecting a total of 869 regulated subsidiaries. Consequently, we can conclude that multinational companies, especially those operating both inside and outside of the regulatory area, are of major relevance for the analysis of the impacts of the EU ETS on firm behavior.

4. Research design

We now proceed to analyzing the causal impact of the EU ETS on treated firms asset bases with a special focus on the differential behaviour of firms pertaining to Global MNEs. In a classic randomized controlled trial (RCT), random assignment of treatment status balances observed and unobserved firm characteristics across the treatment and control group. However, since we are working with observational data, treatment assignment is not random. A simple comparison of means between participating and non-participating firms will thus not yield a reliable estimate of the causal effect of the EU ETS if the distributions of observed and unobserved confounders are not balanced between the two groups. We thus follow a two stage approach proposed by Heckman et al. (1998) that was applied in the context of the evaluation of the EU ETS in similar ways by Koch and Basse Mama (2016) and Zaklan (2016). In the first stage, our goal is to find a subgroup of non EU ETS firms that is very similar to our treated group of EU ETS firms in pre-2005 characteristics. In the second stage, we account for any time-invariant confounders that may remain after the design stage via a Difference-in-Differences (DiD) estimation. Combining the strengths of both strategies enables us to obtain credible estimates of the causal effects of the EU ETS (Blundell and Dias 2009).

4.1. Stage I: Design stage

Our main goal for the design stage is to substantially improve the overlap in covariate distributions between treated firms of the EU ETS sample and untreated firms in the control group (Rosenbaum and Rubin 1983). Balancing on observed covariates will also allow us to balance other firm characteristics that we do not observe, if these are related to our observed covariates. Intuitively, we want to make the two groups as similar as possible in terms of all pre-treatment characteristics that may confound our estimates of the causal impact of the EU ETS on asset bases. For such a sample, it is far less likely that a post-2005 shock will have a systematically different impact on these two groups and thus obscure the estimation of the causal effect.

In order to address this challenge, we exploit the unique design features of the EU ETS to obtain a sample of treatment and control firms that are equivalent in a whole set of potential confounders. In particular, whether a firm is subject to the system is not decided at the firm level, but at the installation level. Also, due to implementation costs, the EU ETS does not comprise all European installations in carbon-intensive industries. Instead, regulatory status of an installation is set via industry specific criteria such as capacity thresholds.[17] For instance, a steel plant will be covered by the EU ETS if its production capacity is above 2.5 tons per hour, whereas for a plant producing ceramic products this threshold will be at 75 tons per day.[18] The exploitation of the EU ETS inclusion criteria along the lines established by Calel and Dechezleprêtre (2016) should allow us, at least in principle, to find a suitable sample of EU ETS and control firms that are very similar in all aspects that matter for investment decisions into their asset bases except for the size of their installations. The key idea here is that our analysis is conducted at the firm level rather than at the plant level. Firstly, investment decisions are taken by the firm that owns the plant, not by the plant itself. Secondly, we can expect asset bases to be determined by a whole range of firm level characteristics (such as asset structure, overall size or the sector and country a firm operates in) and not exclusively by the size of a single installation.

We employ a propensity score approach (Rosenbaum and Rubin, 1985) to construct a sample that balances out our covariates. In our policy context, the propensity score stands for the probability of being subject to the EU ETS conditional on a set of observed characteristics. With a large set of potential confounders, finding an exact match for each ETS firm based on pre-treatment characteristics becomes a difficult task. Propensity scores solve this problem of dimensionality by compressing the information of the continuous variables used in the matching process into a single score. ETS firms are then matched to their closest neighbors from the reservoir of potential control firms based on the score.

[17] Directive 2003/87/EC of the European Parliament and of the Council as of 13 October 2003 amended by Directive 2009/29/EC of the European Parliament and of the Council as of 23 April 2009 provides detailed information on the capacity thresholds.

[18] In terms of combustion processes for power or heat generation, plants only enter the system if their annual thermal input exceeds 20 megawatt.

In order to determine for how many ETS firms we find a suitable neighbor, we assess the overlap in propensity score distributions (also called "common support") between our ETS and non ETS groups. Restricting the sample to those firms with a sufficiently close neighbor based on the propensity score will thus improve balance in covariate distribution. Treated firms from our sample for which we do not find a sufficiently similar counterpart among non EU ETS firms are discarded. Thus, the main challenge is to develop a propensity score specification that balances out the main confounders without sacrificing too much sample size.

However, there are several steps of data preparation and processing that need to be applied before approaching the balancing procedure. Firstly, we use our ownership data to identify all firms that are connected to our treatment group and exclude them from entering the control group. This step is required to ensure that we do not overestimate a potential treatment effect by sampling (potentially) affected firms into a control group. Secondly, we reduce our data to a balanced panel. Assessing the attrition of firms between our treatment group and a control group based on unbalanced data indicated that firms in the control group disappeared at a faster rate than firms in the treatment group.[19] Our solution is to reduce the dataset to firms with data on tangible fixed assets and operating revenue in all periods, thus eliminating any potential attrition bias entirely. Thirdly, we also exclude the very largest of firms (outliers).[20] For those firms any matched control firm would likely differ substantially in treatment-relevant unobserved characteristics (e.g. emission intensity of its assets), otherwise it would have been treated as well. We discuss possible impacts of all of these choices with respect to data processing in the presentation of our main results in section 5.4.

For our processed sample of 326,108 companies, we estimate the propensity score using a probit model. We specify a function of the propensity score that allows us to take

[19] Since the EUTL data we use is reported in 2014, we cannot exclude the possibility that firms that no longer exist in 2014 are also no longer included in this data. Without yearly registry data from the EUTL we cannot distinguish whether this difference is related to the EU ETS or due to the reporting structure of the data.

[20] A firm is considered to be an outlier under this category if it is among the 0.1% firms with the highest or lowest values of either total assets, tangible fixed assets, operating revenue, asset ratio, profit ratio or normalized growth rate in tangible fixed assets in any given year.

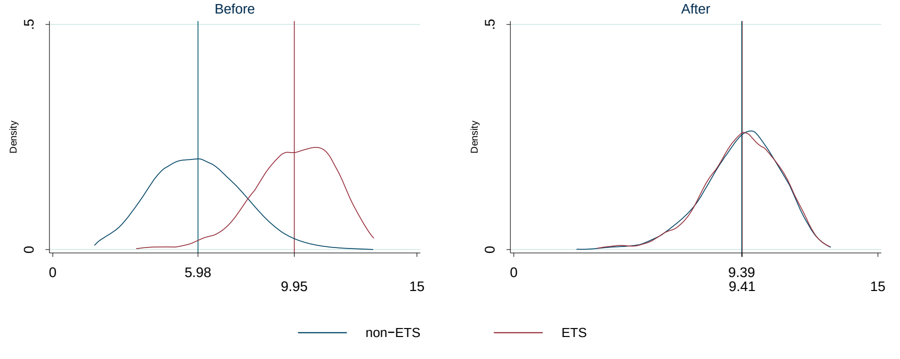
into account an extensive selection of firm level characteristics that can be important determinants of treatment status and our outcome variable, tangible fixed assets. These include relevant potential confounders X such as information on tangible fixed assets, total assets, operating revenue, company age as well as asset, investment and profit ratios for each year of the entire pre-treatment period of 2002-2004. Note that X can only consist of variables that were not affected by the EU ETS. Otherwise, X will be endogenous and will introduce a bias to our subsequent estimates. We account for this by balancing out the covariates only for the pre-treatment period of 2002-2004.

We then enforce an exact match on the sector-country level (NACE Rev. 2 two-digit level) between a given ETS firm and its nearest neighbor based on the propensity score. Utilizing only the closest match for a given treated firm increases the chance of unbiased estimates of the treatment effect, while sacrificing precision. Not allowing for any of the one-to-one pairings to be operating in different sectors or countries is important, as imbalance between treatment and control group in these aspects can be problematic. For instance, a steel company may have very different investment patterns than a company operating in the chemical industry. We further explore this issue in section 5.3 by enforcing exact matching on NACE Rev. 2 three-digit level for different sub-samples.

Next, we trim the sample by restricting it to those EU ETS firms with common support, i.e. to those EU ETS firms for which we do have at least one nearest neighbor from the reservoir of possible control firms that exhibits a sufficiently similar propensity score. Trimming the sample to those companies on support comes at a certain price, i.e. we lose some degree of external validity. Hence, extending our findings to the whole population of regulated EU ETS firms will be somewhat less attainable. The clear benefit of a more consistent subsample is that this loss in sample size and external validity is more than compensated for by the resulting gain in internal validity. This means that our estimates, albeit reflecting the average treatment effect on the treated (ATET) only for a certain subpopulation of the EU ETS, will be more accurate and less prone to potential bias (Dehejia and Wahba 1999, 2002).

To assess the covariate balance, we employ a set of different balance diagnostics. Standardized differences or standardized bias is considered a reliable measure for assessing balance that is robust to changes in sample size and comparable across covariates independent of scale.[21] The results of the balancing process for different samples are reported in Appendix A.2, Table 7 (Sample 1, "Baseline"). For the full range of our covariates in all pre-treatment years, standardized differences are well below 10, indicating a very good balance.[22] We also employ graphical analysis of the covariate distributions before and after balancing. Figure 3 illustrates the overlap in distributions for our variable of interest, tangible fixed assets (in logs) in 2004.[23] Before applying the steps outlined above, distributions between the two groups, EU ETS and non EU ETS firms, are significantly different. After balancing, however, they are very similar in terms of their mean, variance and skewness.

Figure 3: Tangible fixed assets (in logs) in 2004 before and after balancing



Matching a suitable neighbor to a regulated firm was not possible in all cases. Based on our total sample of 7.279 EU ETS firms, 1.519 firms did not report verified emissions

[21]It is defined as

$$d = 100(\overline{x}_1 - \overline{x}_{0M})/\sqrt{\frac{s_1^2 + s_{0R}^2}{2}}. \quad (1)$$

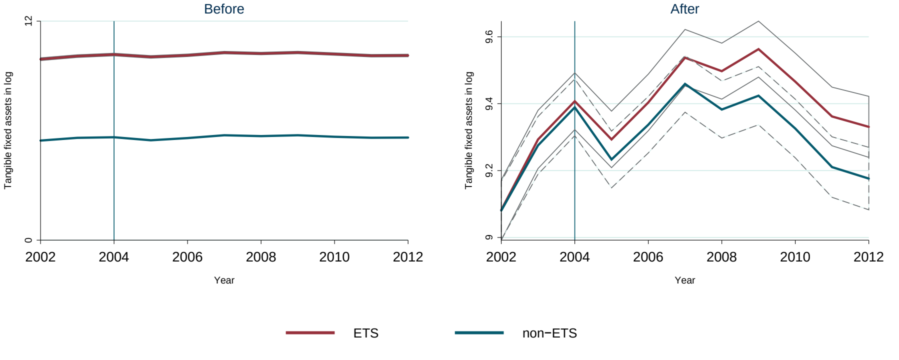
where for each covariate, $\overline{x}_1$ and $\overline{x}_{0M}$ are the sample means in the treated group and matched control group and s_1^2 and s_{0R}^2 are the sample variances in the treated group and control reservoir (Rosenbaum and Rubin, 1985).

[22]Suggested maximum values of standardized differences range from 10 to 25 percent. Thus, taking into consideration additional measures of balance is especially important in case these limits are surpassed (Garrido et al., 2014).

[23]While we only report tangible fixed assets in logs here, the visual impression is essentially similar for all covariates. Additional visualizations are provided in Appendix A.1.

in either of the two treatment periods. 537 were incorporated into ORBIS only in the post-treatment period, meaning after the end of 2004. 185 of them did not report plausible financial data (e.g. negative assets or unplausibly large jumps in variable values of consecutive years). Due to our outlier correction, 516 very large firms are removed from the sample. Also, we are forced to exclude 2.605 firms that either did not pass our panel attrition test or did not have any pretreatment data.[24] As expected, some dissimilarities remain. The remainder of 1.915 firms did pass both tests, but for 594 firms we could not find a matching partner (off support). Hence, we establish a sample that consists of 1.321 EU ETS firms and 1.321 non EU ETS firms that is balanced in all potential key confounders for the entire pre-2005 period.

Figure 4: Means over time: Tangible fixed assets in log



As a first intuitive step to look into the effects of the EU ETS on regulated firms' asset bases, we plot the mean of tangible fixed assets (in logs) over time for our groups of EU ETS and non EU ETS firms. Figure 4 (Before) shows that, before matching, both groups differ substantially in the size of their respective asset bases. Next, we assess our sample of matched EU ETS and non EU ETS companies. Figure 4 (After) shows that the design stage has provided us with two groups that are very similar in terms of their pre-treatment asset bases. Also, both groups do not seem to exhibit any different trend

[24]The figures reported here are subject to the order in which we apply the steps of the procedure. Also consider that allowing these firms to enter our design stage would not necessarily mean that we could find a suitable match for them.

behavior previous to 2005. This strongly supports our assumption of a common trend. Most notable though is that after the introduction of the EU ETS in 2005, the levels of tangible fixed assets evolve differently in treatment and control group. The divergence becomes more apparent from 2008 onwards, which marks the beginning of the second phase of the system.

4.2. Stage II: Causal analysis

Our objective in the second stage is to obtain the average effect of the EU ETS on regulated firms' asset bases (average treatment effect on the treated, ATET). Employing DiD, i.e. differencing post-policy outcomes with respect to pre-policy outcomes, aims at removing any remaining time-invariant unobservable differences (e.g. long term emission intensities). While our general approach of combining matching with DiD follows Heckman et al. (1997) as summarized in Blundell and Dias (2009), our methodology and notation for DiD follows Lechner (2011). Capital letters denote random variables and small letters denote specific values or realizations.

$$
\begin{aligned}
E\left[Y_t^1 - Y_t^0 | D=1\right] &= E\left[E(Y_t^1 - Y_t^0 | X = x, D = 1) | D = 1\right] \\
&= E_{X|D=1}\theta_t(x) \qquad (2)
\end{aligned}
$$

where D is the binary treatment variable, i.e. $d \in 0, 1$. Y_t^d denotes the outcome that would be realized for a specific value of d in period t, thus Y_t^1 corresponds to the outcome of a firm in the post-treatment period t if it were regulated by the EU ETS. x refers to particular values of random variables X.

Since we do not observe post-treatment outcomes for the treated firms if they had not been treated, i.e. the counterfactual $Y_t^1|D = 0$, a set of identifying assumptions must be fulfilled to allow for a causal interpretation of the obtained ATET.

The key assumption of the DiD-approach, as outlined by Lechner (2011), is the *Common Trend Assumption*. The assumption implies that, had the treated not been subject to the treatment, both subpopulations defined by $D = 1$ and $D = 0$ would have experienced the same time trends conditional on X. While this counterfactual scenario cannot be reproduced in our empirical setting, Figure 4 (After) shows a common trend of tangible fixed assets in both groups in the pre-treatment period (2002-2004), thus lending support to the assumption. The *Stable Unit Treatment Value Assumption (SUTVA)* implies that there are no relevant interactions (spillovers) between members of the two groups. This poses some challenges in the context of firm-level data. Firstly, as matching of treatment and control group becomes more accurate, the more likely it becomes that firms are competitors. We adress this issue by balancing out the sector-country distributions using the broader NACE 2-digit sector definition.[25] Secondly, if firms are connected in business groups, direct spill-over effects could occur that would render all connected firms unusable as controls. As we discussed in the previous section, we prevent all connected firms from entering the control group.

Since we achieve very good balance for a wide range of important covariates, we refrain from including them in the model. Since the post-2005 covariates are potentially affected by the EU ETS, including them would also potentially violate the standard *Exogeneity Assumption*, which states that covariates X are not influenced by the treatment. We also assume the *Absence of anticipation effects*. Since the EU ETS Directive was adopted in October 2003, in principle, firms could have adjusted their asset structure in anticipation of the start of the scheme in 2005. Our approach may then not capture the entire ATET, but underestimate it. To address this to some degree, we also balance out covariates for the year 2002. In addition, treatment intensity was still not certain due to the complexity of the rules. This raises doubts on whether firms had an actual incentive to pursue an active strategy or rather wait for the policy to manifest itself completely. For instance, firms could have expected net benefits from the policy via windfall profits obtained from free allocation. Firms also could have expected net costs. So even if self-selection was the case, it could could have happened in both directions.

To implement the DiD identification strategy we apply the common linear regression model to our balanced sample and since we used one-to-one nearest neighbor matching

[25] Under robustness, we put more emphasis on sector-wise similarities using the more detailed NACE 3-digit definition.

without replacement, there are no weights used in the final estimation.

$$
\begin{aligned}
y_{it} = \alpha + \alpha_i + \beta ets_i + \gamma period_t + \delta treat_{it} \\
+ \phi_1 mne\_link_{it} + \phi_2 \left[mne\_link_{it} * treat_{it}\right] \\
+ \varphi_1 mne\_nolink_{it} + \varphi_2 \left[mne\_nolink_{it} * treat_{it}\right] \\
+ \eta[industry_i * year_t] + \epsilon_{it}
\end{aligned}
\tag{3}
$$

Here y_{it} denotes the tangible fixed assets of a given company $_i$ at time $_t$ in logs, α is a constant, α_i is the firm-level fixed effect, $treat_{it}$ is the interaction of ets_i and $period_t$, $year_t$ are yearly effects, $industry_i$ are sector-specific effects and ϵ_{it} stands for the error term. After demeaning the variables using the *within* transformation, the resulting fixed effects model only consists of the yearly effects (unreported) and the interaction terms. Standard errors are clustered at the firm level.

5. Results

5.1. Baseline results

For our baseline sample we estimate three models: Model one contains the treatment dummy for measuring the ATET. Model two contains both the treatment dummy as well as an interaction term of the treatment effect with global MNE status. Model three employs two interaction terms instead of one, thus allowing us to differentiate between the two types of multinational company structures, i.e. firms that are part of a global MNE with a functional link, and firms that are part of a global MNE without such a link. Since we are using tangible fixed assets in logs, our DiD estimator can be interpreted as the ATET given in percentage terms.

The empirical results reported in Table 1 indicate that the EU ETS had a strongly significant positive effect on the treated firms' tangible fixed assets in the post-treatment period from 2005 to 2012. For each model, the DiD estimator yields a treatment effect that corresponds to an increase of treated firms' asset bases in the range of 10.1% to

Table 1: Baseline effects

	(1)	(2)	(3)
ETS treatment effect	0.101***	0.112***	0.110***
Global MNE and treated		−0.042	
Global MNE without functional link and treated			−0.094**
Global MNE with functional link and treated			0.016
Firms (T+C)	2642	2642	2642

Significance levels: * p <0.10, ** p <0.05, * * * p <0.01

Standard errors are clustered on the firm level.

Sector-Year fixed effects and firm-level fixed effects included.

11.2%. Note that the estimates are consistently significant at the 1% level. Interestingly, model 2 results do not indicate that MNE status per se explains a different treatment effect for this subpopulation of our sample. Although at a sizeable negative magnitude of minus 4.2%, the interaction term is insignificant.

The picture becomes clearer by looking at the results obtained from model 3. For MNEs with a functional link, the interaction term effect is not only insignificant but also of very low magnitude (0.016%), indicating that these firms do not behave differently than the remainder of treated firms. However, multinationals without a functional link do exercise a behavior that is significantly different from the rest of the sample. The interaction effect is significant at the 5% level and corresponds to a 9.4% decrease in tangible fixed assets relative to the remainder of the sample. For model 3, we can thus cautiously interpret these results in the following way: whereas most treated firms increased their tangible fixed asset bases, firms that are part of a multinational network without a functional link did so by a mere 1.6%.

Table 2 shows these effects separately for the two regulatory phases of the EU ETS. The intuition derived from Figure 4 is confirmed in the sense that the ETS treatment effect in phase II is substantially more pronounced. In phase I, for each of the three models, the magnitude of the ATET ranges from 5.6 to 6.2%. In phase II, the treatment effect is considerably higher, ranging from 12.8 to 14.6%. Estimates for both phases are significant at the 1% level. Again, model 3 results indicate that firms that are part of a global network without a functional link seem to react significantly different to the EU

Table 2: ETS impact by phase

	(1)	(2)	(3)
ETS Phase I treatment	0.056^{***}	0.062^{***}	0.058^{***}
Global MNE and treated (I)		-0.027	
Global MNE without functional link and treated (I)			-0.061
Global MNE with functional link and treated (I)			0.027
ETS Phase II treatment	0.128^{***}	0.146^{***}	0.144^{***}
Global MNE and treated (II)		-0.061	
Global MNE without functional link and treated (II)			-0.121^{**}
Global MNE with functional link and treated (II)			0.000
Firms (T+C)	2642	2642	2642

Significance levels: * p <0.10, ** p <0.05, * * * p <0.01

Standard errors are clustered on the firm level.

Sector-Year fixed effects and firm-level fixed effects included.

ETS than other firms. In phase II, the interaction term is significant at the 5% level and corresponds to a 12.1% decrease in tangible fixed assets relative to the rest of the sample. Hence, the phase II treatment effect for these firms corresponds to an increase in asset bases by only 2.3% (14.4% for other treated firms). For phase I, the magnitude of the effect even points to a slight decrease in assets by -0.3% (5.8%). However, the estimate for the interaction term is statistically insignificant, which may suggest that global MNEs still behaved similar to other companies in phase I.

5.2. Heterogeneity of treatment effects

To assess if the treatment effects we analyzed in the previous subsections indeed manifest themselves heterogeneously across sectors and firm types, we apply both stages, design stage and causal analysis, separately to three subgroups of firms: firms pertaining to the manufacturing sector, manufacturing firms considered to be at high risk of carbon leakage according to the carbon leakage list (CLL) of the EU, and energy companies. Balancing results for these subsamples are displayed in Appendix A.2, Table 7. For the manufacturing and the energy sample most covariates are very well balanced with standardized differences well below 10, although covariate balance inevitably suffers in the smaller samples.[26]

Table 3: Effect heterogeneity

	(1) Baseline	(2) Manufacturing	(3) CLL only	(4) Energy
ETS treatment effect	0.110***	0.121***	0.216***	0.128**
Global MNE without functional link and treated	−0.094**	−0.100**	−0.052	−0.136
Global MNE with functional link and treated	0.016	0.028	0.087	−0.048
Firms (T+C)	2642	1670	1184	596

Significance levels: * p <0.10, ** p <0.05, * * * p <0.01

Standard errors are clustered on the firm level.

Sector-Year fixed effects and firm-level fixed effects included.

Secondly, we compare the estimation results for these subsamples with our baseline sample. This is reported in Table 3. For all of the three subsamples, the ETS treatment effect remains highly significant and at a sizeable magnitude.[27] The DiD estimates point towards a positive effect, i.e. an increase of asset bases ranging from 12.1 to 21.6%.

The interaction term for multinational firms without a functional link remains negative for all subsamples with magnitudes in the range of -10.0 to -13.6%. Important to consider here are the substantial differences in significance levels. Whereas the effect is statistically significant for manufacturing firms at the 5% level (baseline: significant at the 5% level), the effect is insignificant for the CLL-only sample and the energy firms.

Overall, the results for the baseline sample seem to be driven by the behaviour of manufacturing firms. The results indicate that, whereas most treated manufacturing firms increased their tangible fixed asset bases by 12.1% compared to the control group, firms that are part of a multinational network without a functional link did only so by a mere 2.1%. For energy and/or trade intensive firms (CLL-only sample) the effect of the EU ETS seems to be substantially larger. For neither the energy nor the CLL-only sample, we can attest that multinational firms without a functional link reacted differently than other treated firms. However, the small sample size of the energy sample and particular the strong covariate imbalance in the CLL-only sample suggest caution when interpreting the results. Due to these challenges for the two smaller subsamples

[26] We also find graphical evidence which lends support to the assumption of a common trend in average outcomes for all three subsector samples.

[27] Manufacturing and CLL-only samples: Significant at the 1% level. Energy: Significant at the 5% level.

(energy companies and firms with a supposedly high relocation risk), we now focus on the more reliable manufacturing sample and test if the results hold under more restrictive and more relaxed conditions.

5.3. Robustness

To assess the robustness of the results we need to verify if the main identifying assumptions, unconfoundedness and the stable unit treatment value assumption, are plausible in our specific policy context. One challenge to the unconfoundedness assumption is the potential presence of unobserved covariates that directly affect treatment status and our outcome variable, tangible fixed assets in logs, thus confounding our post-2005 estimates (omitted variable bias). Hence, the question arises if regulated and non-regulated firms that are observationally equivalent are also similar in terms of unobserved characteristics. This can be tested to a certain degree by assessing the results of our design stage.

Table 8 in Appendix A.2 reports balancing results both for financial covariates that entered the design stage and for those additional variables that were not part of the process. As depicted in section 5.4, the simple balancing sample requires balance only on 2004 firm characteristics, but also leads to firms in both groups being very similar for their respective covariates in 2003 and 2002.[28] This finding highlights that achieving covariate balance for a given year is conceivable to produce balance in these covariates for other pre-treatment years that we do not observe, i.e. years previous to 2002. However, unobserved covariates that are not part of the design stage at any point in time might still exhibit meaningful imbalances. For the purpose of looking into this aspect, we assess the balance for a covariate that did not enter the design stage at all: the number of employees in logs. Distributions for this covariate are actually very similar between the two matched groups.[29] This gives us some indication that balancing on observables likely produced a sample that is actually balanced in at least some unobserved covariates as well. Another type of omitted variable bias may arise if the level of information we capture through

[28] For instance, we achieve an excellent balance for tangible fixed assets in 2003 and 2002 (standardized differences -0.4 and 0.5 respectively), although our pre-treatment outcome only entered the design stage for the year 2004.

[29] Results are available from the authors upon request.

our covariates is not precise enough. Again, we compare two types of firms that are observationally almost identical, but here, an important layer of information is missing which then may explain the effect we attribute to the EU ETS. This could be the case for non-financial variables, i.e. the definition of sector affiliation and firm structure.

In terms of sector affiliation, we enforced exact matches on the country-sector level, employing the 2-digit NACE Rev. 2 codes. This information may not be refined enough. For instance, the category ”20 - Manufacture of chemicals and chemical products”, contains both firms that mainly produce synthetic rubber but also firms that manufacture paints and coatings. However, rubber producers could be systematically more likely to be subject to the EU ETS and at the same time possess different patterns with regards to their investment in asset bases than paint manufactures. Also, in terms of firm structure, our research question rests on the idea that being part of a network enables firms to adapt their asset bases more flexibly, e.g. by shifting resources more easily within networks. These aspects could create imbalances between treated and control firms with respect to key confounders and thus potentially obscure our estimate of the treatment effect. One could argue that these covariates are very relevant and that imbalances might obscure our estimates. For instance, firm structure may not only be a confounder by itself, but instead also be associated with other potential unobserved confounders that we may not balance out yet entirely, such as access to capital markets, or management quality and dimensions like overall performance and growth prospects of a company.

In order to address these potential sources of bias, we further refine the exact matching approach that we employed for the design stage as outlined in section 4.1 and are more restrictive about which EU ETS and non EU ETS firms are allowed to be matched. Table 4 compares our baseline results with the results obtained for the two samples with more demanding design stage constraints. Sample 2 again requires exact matching on the sector-country level. However, firms can now only be matched within smaller, 3 digit NACE subsectors. Sample 3 requires exact matching on the sector-country-firm type level. Hence, ETS and non EU ETS firms can only be matched if they not only operate in the same country and NACE 2 digit sector, but also had the same firm structure in

2004, i.e. either had no ownership links at all (independent companies) or were part of the same kind of firm network (national, EU, global with or without a functional link).

Table 4: Tightening the sample restrictions - manufacturing

	(1) Manufacturing	(2) NACE 3-digit	(3) Balanced MNE status
ETS treatment effect	0.121***	0.153***	0.113***
Global MNE without functional link and treated	−0.100**	−0.147**	−0.139***
Global MNE with functional link and treated	0.028	0.061	0.021
Firms (T+C)	1670	1050	1574

Significance levels: * p <0.10, ** p <0.05, * * * p <0.01

Standard errors are clustered on the firm level.

Sector-Year fixed effects and firm-level fixed effects included.

In Table 4, the DiD estimator yields a positive EU ETS treatment effect corresponding to an increase of asset bases in the range of 11.3% to 15.3%. Note that these estimates are all highly significant at the 1% level. Both more restrictive samples seem to confirm the findings of the original manufacturing sample. Noteworthy are the different magnitudes of the terms. For these two samples, it seems that treated multinational companies without a functional link react very differently compared to other treated firms. For the NACE 3-digit sample, they only increased their tangible fixed assets by 0.6%. For the sample that requires balance in MNE status, we even observe a decrease in assets by 2.6%. The latter finding points towards an erosion of the asset bases of theses companies caused by the EU ETS.

These results should be interpreted with some caution. Compared to our original sample we sacrifice some degree of covariate balance and sample size for attaining samples that are more stringent with regards to sector affiliation or firm structure. For the NACE 3-digit sample, only pre-2005 tangible fixed assets are balanced.[30] The results generally support our previous findings, although we do observe some modest differences.[31] We can therefore have some confidence that our initial results are not the product of a bias arising from insufficient balance in terms of observable sector affiliation or firm structure.

Next, we assess how our own methodology of identifying business groups over time

[30] Again, we do find graphical evidence supporting the common trend assumption.

[31] Consider that we cannot determine whether these differences stem from a better balance in sector or firm structure related covariates, or other differences in sample composition.

Table 5: Comparing structural assumptions - manufacturing

	(1) Manufacturing	(2) Constant 2004	(3) Constant 2012
ETS treatment effect	0.121***	0.098***	0.118***
Global MNE without functional link and treated	−0.100**		
Global MNE with functional link and treated	0.028		
Global MNE without functional link and treated		−0.089	
Global MNE with functional link and treated		0.192*	
Global MNE without functional link and treated			−0.135**
Global MNE with functional link and treated			0.065
Firms (T+C)	1670	1670	1670

Significance levels: * p <0.10, ** p <0.05, *** p <0.01

Standard errors are clustered on the firm level.

Sector-Year fixed effects and firm-level fixed effects included.

compares to more static definitions of MNEs. Until now, we identified ownership structures for each year and company in the period of 2002-2012. However, firstly, one could argue that ownership structure in the year 2012 is a more robust definition of the group. Quality and extend of the ownership data in ORBIS increases over the years and a dynamic definition might then not capture the true affiliation in some years.[32] This could influence our results if the data quality differs between EU ETS and non ETS firms. For this case, we use the ownership information in the year 2012 and assume this information for all years in 2002-2012. Secondly, group changes themselves might also be influenced by the EU ETS itself and thus may confound our interaction effect. For that case, we use the ownership information in 2004 and again assume this information as constant for all years. However, this approach could lead us to overwriting high quality information in subsequent years with old or no information from the year 2004. Results in Table 5 show that if we just use 2012 information, our previous effects are broadly confirmed and even point towards a decrease of the assets of the subgroup of global MNE without a functional link by -1.7%. However, our results for using 2004 information do confirm the overall treatment effect, but the differential effect for the subgroup is now insignificant. We can thus conclude that the group definition does influence our results to some degree.

[32]For instance, a firm that is owned by a global MNE with a functional link in the years 2002-2012, but has only information on ownership status for 2012 would not be deemed an MNE for most years.

5.4. External validity

In section 4.1, we outlined that obtaining a smaller sample that is more suitable for causal analysis comes at the cost of sacrificing a certain degree of external validity. We demonstrate this tradeoff by comparing our baseline sample with our original sample of matched EU ETS firms in terms of number of firms and emissions. Our baseline sample contains 1.321 (18%) of the 7279 EU ETS firms that we matched to ORBIS. This corresponds to only 4% of the total greenhouse gas emissions covered by the system between 2005 and 2012. Note that we originally identified 7.279 firms as subject to the EU ETS according to EUTL and ORBIS based information, but fewer are actually relevant for our analysis. We lost a total of 5.958 firms due to our corrections for outliers, panel attrition, inactivity in the regulatory phases or the simple fact that we could not find a suitable matching partner. Out of these firms, the 516 size outliers constitute only 7% of our original population, but represent 49% of total emissions. Also, 2.605 firms that either did not pass our panel attrition test or did not have any pre-treatment data produce 25% of emissions. Given the fact that treatment assignment is clearly not random but based on capacity thresholds, it is plausible to find a suitable control group for small and medium sized emitters, whereas it can be considered highly unlikely that we would find a sibling for a very big polluter with accordingly high levels of e.g. assets, profits or revenues outside of the EU ETS. These large EU ETS regulated companies are simply too different from untreated firms outside of the EU ETS. Therefore, we focus on a sample of firms where potential confounders are balanced after applying our design stage.

However, our assumptions on which firms qualify as suitable matching partners might be too restrictive and sacrifice more sample size than necessary. For instance, one could argue that achieving covariate balance for the last pre-treatment period in 2004 is sufficient to balance out potential confounders. Also, different survival rates between matched ETS firms and their counterparts might not distort the treatment effect. We therefore, in a stepwise manner, relax our assumptions on the importance of accounting for outliers, non-surviving firms, and connected firms, as well balancing on potential confounders in all pre-2005 periods. This allows us to increase our sample size and corresponding emissions substantially and to investigate if our findings hold in less restrictive samples, but makes the results also more difficult to interpret. In addition, we can assess how excluding certain types of firms affects our results. Our least restrictive baseline sample, which requires matching only on covariates in 2004 during the design stage, contains 2839 ETS firms which are responsible for 31% of the relevant emissions. Again, for 594 firms which account for 27% of relevant emissions we do not find a suitable match. Another 1514 firms corresponding to 18% of emissions do not have pre-treatment records for our outcome variable. As outlined before, we focus our analysis on the manufacturing subsample, which, in its most restrictive form contains 835 companies, whereas the less restrictive design stage allows us to obtain a sizable sample of 1677 companies. Table 6 reports estimation results for the manufacturing sample and three manufacturing samples with fewer restrictions. We contrast the original effects with estimates from larger, more representative, albeit potentially less consistent samples. Balancing results for these samples are presented in Appendix A.2, Table 8 (columns 4 to 6). Despite some differences compared to the manufacturing baseline (column 3), most of the covariates are well balanced. In the case of the samples with large firms and without restrictions, balance even improves for some covariates to some degree. This can be attributed to the fact that we now are less restrictive about the choice of the matching partner for each treated firm.[33]

Table 6: Relaxing the sample restrictions - manufacturing

	(1) Manufacturing	(2) With large firms	(3) Without restrictions	(4) Simple balancing
ETS treatment effect	0.121***	0.148***	0.136***	0.133***
Global MNE without functional link and treated	−0.100**	−0.094**	−0.049	−0.053
Global MNE with functional link and treated	0.028	0.042	0.043	0.012
Firms (T+C)	1670	1746	2860	3352

Significance levels: * p <0.10, ** p <0.05, * * * p <0.01

Standard errors are clustered on the firm level.

Sector-Year fixed effects and firm-level fixed effects included.

Going from left to right in Table 6, we relax the restrictions stepwise. Sample 2 allows for very large firms, Sample 3 for very large firms, non-survivors and connected companies, and Sample 4 allows for all these firms to enter the design stage and only requires a

[33] In unreported graphical analysis we find evidence that supports our common trend assumption in these samples; i.e. parallel trends between ETS and non ETS groups in pre-treatment outcomes.

balancing on 2004 firm characteristics. In Table 6, for all four samples the DiD estimator yields a positive EU ETS treatment effect corresponding to an increase of asset bases in the range of 12.1 to 14.8%. Also, the estimates given for the EU ETS treatment effect remain highly significant at the 1% level.[34] The results also show that we can extend the finding of the differential effect for multinational firms without a functional link to Sample 2, which contains very large firms. This is important as this sample stands for a more relevant amount of emissions covered by the EU ETS. In this particular sample, we can cautiously interpret the estimates in a sense that while the remainder of the treated firms did increase their tangible fixed asset bases by 14.8%, treated MNEs without a functional link did so only by 5.4%. However, the term is insignificant in Samples 3-4. Thus, we can extend this finding only to a sample that is more sizeable in terms of emissions but not in terms of the number of firms. Also, unreported analysis for our baseline sample containing all sectors shows that this only holds true for the manufacturing sample as the differential effect disappears in all bigger samples. In contrast, the overall positive effect corresponding to asset increases remains highly significant in all samples, underlining the relevance of this finding.

6. Discussion

The EU ETS is the largest cap-and-trade program in the world. Negative competitiveness impacts on regulated businesses are discussed since its inception. Most notably, the concern is widespread that carbon leakage might occur through relocation decisions of regulated firms which could render the policy ecologically ineffective and economically detrimental. Drawing on a newly constructed, broad international dataset that covers all firms subject to the EU ETS and links regulatory information with financial statements and ownership details, this study investigates the evolution of firms' holdings of tangible fixed assets as an indicator for processes of industrial relocation.

[34] Interesting to note is that including size outliers into the sample drives the treatment term up from a magnitude of 11.1 to 14.8%. This suggests that a small number of large firms indeed influences the means in both groups post-2005 and may thus lead us to exaggerate the effect for the remainder of the sample.

Matched difference-in-differences estimates provide robust evidence that casts severe doubt on the idea of an erosion of European asset bases. Baseline results indicate that the EU ETS led, on average, to an increase of treated firms' tangible fixed asset bases of 11,1%. This finding complements empirical evidence on the causal effects of the EU ETS on firm's competitiveness. Comprehensive surveys by Martin et al. (2014) and Martin et al. (2015) demonstrate that the reported average propensity to downsize in response to the EU ETS or relocate operations has been clearly below a 10 percent cut in production or employment. Petrick and Wagner (2014) also found no evidence for Germany that suggests a downsizing of operations via a reduction in employment or gross output. Our primary findings are also in line with the evidence obtained by novel studies that focus on the causal impact of the EU ETS on firms' location decisions, outward foreign direct investment and emissions leakage. Koch and Basse Mama (2016) find for Germany that, on average, treated firms did not increase their outward FDI. Dechezleprêtre et al. (2015) conclude that the EU ETS has not induced global shifts in emissions within multinational companies. Borghesi et al. (2016) show for Italy that, on average, treated firms did not increase the amount of foreign affiliates outside the regulated area. Our paper is consistent with these findings and provides a new perspective on the asset bases of companies regulated by the EU ETS.

Firstly, our study suggests that firms, on average, increase their operations, i.e. the value of production capacities such as plants, machinery and equipment, in Europe in response to the EU ETS rather than downsizing them. Clearly, this appears to be a reaction to the regulatory pressure by the EU ETS. Even for those companies deemed to be at a very high risk of carbon leakage, we detect no signs of asset erosion but, on the contrary, comparatively substantial asset increases. Along the lines of Martin et al. (2014) and Martin et al. (2015), this may call into question the efficiency of the rules to allocate free emission permits to such firms. If industry groups exaggerate the threat of relocation to obtain substantial overcompensations, these funds will not be available for other purposes. Unfortunately, our data does not allow to differentiate between the analyzed production-related assets. Given that studies with emissions data do find a reduction of emissions by treated firms that can be attributed to the EU ETS (Petrick and Wagner 2014 for Germany and Wagner et al. 2014 for France), these asset increases might be related to the employment of abatement technology, although a thorough assessment requires more comprehensive data. Since the EU ETS is mainly regulating capital-intensive industries, firms may be facing very high relocation costs that keep them from any substantial relocation and instead incentivize them to maintain or increase their assets.

Secondly, we focus our analysis on firms with, as we argue, particularly low relocation costs: firms that are part of globally operating business groups. If relocation takes place on an important scale via this channel, we should observe asset erosion. Interestingly, those treated companies that we would expect to have very low costs to relocate, i.e. firms pertaining to a global network with at least one firm operating in the same sub-sector but outside the regulated area, clearly increased their asset bases in response to the EU ETS along with other treated firms. In terms of our research question, this is an important finding contradicting the idea of asset erosion. It is particularly relevant for the manufacturing sector, which can be subject to international competition and thus might be at risk of industrial relocation. As we show, this company type accounted for 60.8% of manufacturing emissions under the EU ETS in 2012.

However, narrowing down our analysis to the manufacturing sector, we find that a subgroup of firms pertaining to global business groups with no functional link appears to react differently than the rest of the sample. While most treated firms increased their assets in response to the EU ETS by 12.1%, the subgroup did so only by a mere 2.1%. The effect still suggests that these firms neither downsize their operations nor that they let their assets erode, although they do seem to react differently. This might indicate a shift in investment priorities for this particular subgroup. Assessing the robustness of our findings, we show that the differential effect holds only in samples where we place emphasis on internal validity. However, the results cannot be extended to more sizeable samples and depend to some degree on the definition of ownership. In contrast, the overall effect of a sizeable asset increase can be extended to all samples. The finding complements insights provided by Koch and Basse Mama (2016) and Borghesi et al. (2016), which show that, while the large majority of firms is unresponsive, some small subgroups with very low capital intensities or high trade intensities may behave differently and, in their case, relocate to a certain degree. Similar to the cited studies, we find that our subgroup does not correspond at all to an important amount of emissions under the EU ETS.

Taking all these insights together from a theoretical point of view, benefits that firms obtain from the policy may outweigh its costs. On the benefits side, firms may appreciate the stability provided by the EU ETS compared to the regulatory uncertainty on carbon policy in other world regions. Firms may also expect long term gains in competitiveness or may have obtained windfall profits from free allocation. Costs on the other hand seem to have been bearable with persistently low permit prices and high levels of free allocation.

Our findings may also, along with the novel literature, open up new avenues for future research. For instance, studies will have to clarify if the findings hold true for future phases of the EU ETS, i.e. if an increased rigidity undermines firm competitiveness and provides incentives for asset erosion or, on the contrary, improve their competitiveness and thus increase the European asset base.

To conclude, the magnitude of asset erosion in phases I and II of the EU ETS appears to be very limited if not negligible. Very much in line with the extant empirical literature, we find that claims of a substantial industrial relocation caused by the EU ETS that would manifest itself in the erosion of European assets and, consequentially, emissions leakage, seem to be overstated. On the contrary, even for companies deemed to be at very high risk of carbon leakage, we detect no signs of asset erosion but comparatively substantial asset increases.

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A. Appendix

A.1. Figures

Figure 5: Tangible fixed asset ratio in 2004 before and after balancing

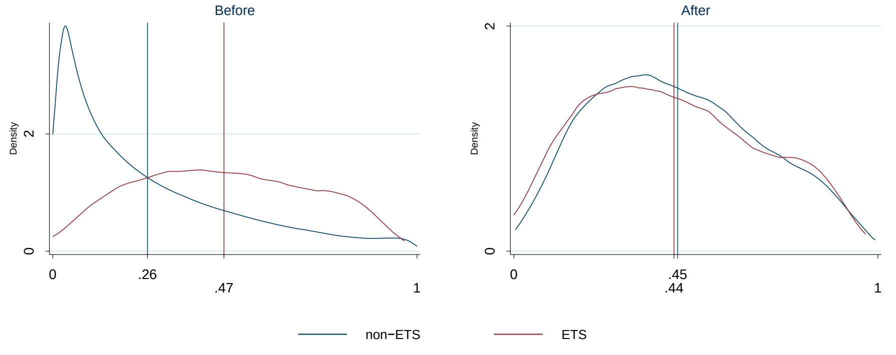
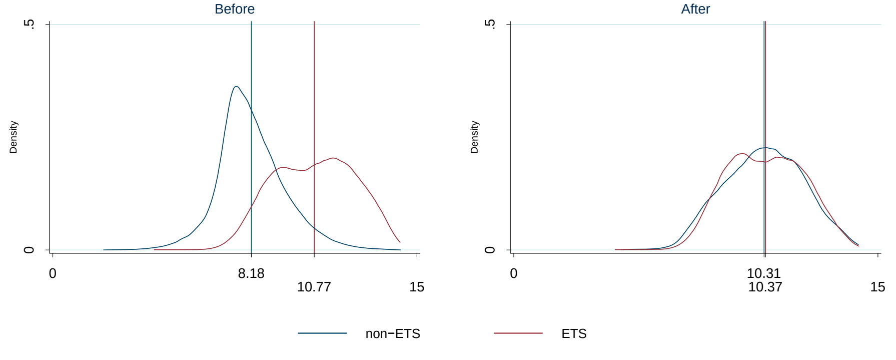


Figure 6: Operating revenue (in logs) in 2004 before and after balancing



A.2. Covariate balancing - Standardized differences

Table 7: Subsamples to assess effect heterogeneity

	(1) (Baseline)	(2) (Manufacturing)	(3) (CLL only)	(4) (Energy)
Very large firms excluded	✓	✓	✓	✓
Firms connected to the treatment group excluded	✓	✓	✓	✓
Firms with missing asset data excluded	✓	✓	✓	✓
Balancing on 2004 MNE status				
Sector	All	Manuf.	CLL only	Energy
NACE code	2-digit	2-digit	2-digit	2-digit
Caliper	0.2	0.2	0.2	0.2
On support	325514	90289	46659	1580
Treatment group	1321	835	592	298
Control group	1321	835	592	298
Off support	594	377	399	222
Tangible fixed assets (in logs), 2004	1.0 | *in*	−0.1 | *in*	−0.6 | *in*	4.6 | *in*
Tangible fixed assets (in logs), 2003	1.0 | *in*	1.8 | *in*	−0.9 | *in*	4.8 | *out*
Tangible fixed assets (in logs), 2002	0.1 | *in*	2.2 | *in*	−1.6 | *in*	3.3 | *out*
Total assets (in logs), 2004	7.2 | *in*	4.5 | *in*	9.4 | *in*	8.5 | *in*
Total assets (in logs), 2003	7.3 | *in*	5.4 | *in*	9.2 | *in*	7.5 | *out*
Total assets (in logs), 2002	7.1 | *in*	6.6 | *in*	10.1 | *in*	9.0 | *out*
Tangible fixed asset ratio, 2004	−5.7 | *out*	−10.1 | *out*	−24.4 | *out*	1.4 | *out*
Tangible fixed asset ratio, 2003	−5.1 | *out*	−5.5 | *out*	−22.0 | *out*	2.5 | *out*
Tangible fixed asset ratio, 2002	−6.1 | *out*	−6.2 | *out*	−25.8 | *out*	0.8 | *out*
Operating revenue (in logs), 2004	4.0 | *in*	6.6 | *in*	12.5 | *in*	5.0 | *in*
Operating revenue (in logs), 2003	4.1 | *in*	6.7 | *in*	11.2 | *in*	5.2 | *out*
Operating revenue (in logs), 2002	3.8 | *in*	6.6 | *in*	11.9 | *in*	3.8 | *out*
Profit ratio, 2004, winsorized	5.4 | *in*	−11.7 | *in*	−4.6 | *in*	28.1 | *in*
Profit ratio, 2003, winsorized	−1.3 | *in*	−15.2 | *in*	−14.8 | *in*	17.1 | *out*
Profit ratio, 2002, winsorized	−2.1 | *in*	−14.1 | *in*	−15.1 | *in*	16.1 | *out*
Investment ratio, 2004	−2.9 | *in*	−12.7 | *in*	−6.8 | *in*	4.1 | *out*
Investment ratio, 2003	3.0 | *in*	−7.7 | *in*	−8.4 | *in*	3.9 | *out*
Date of incorporation	−2.1 | *in*	0.9 | *in*	−3.4 | *in*	−5.6 | *in*

Treatment groups include only firms known to have been active in both phases of the EU-ETS.

(out) indicates variables that were not part of the balancing process.

Corrections done in all samples: pre-balancing max value threshold, exclusion of firms with implausible data.

Significance levels: $*$ p <0.10, $**$ p <0.05, $***$ p <0.01

All samples based on 1-1 nearest neighbour matching, exact matching on country and sector.

Table 8: Manufacturing samples

<table>
<tr><th></th><th>(1)
(Balanced MNE status)</th><th>(2)
(NACE 3-digit)</th><th>(3)
(Manufacturing)</th><th>(4)
(With large firms)</th><th>(5)
(Without restrictions)</th><th>(6)
(Simple balancing)</th></tr>
<tr><td>Very large firms excluded</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Firms connected to the treatment group excluded</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td></tr>
<tr><td>Firms with missing asset data excluded</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td></tr>
<tr><td>Balancing on 2004 MNE status</td><td>✓</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sector</td><td>Manuf.</td><td>Manuf.</td><td>Manuf.</td><td>Manuf.</td><td>Manuf.</td><td>Manuf.</td></tr>
<tr><td>NACE code</td><td>2-digit</td><td>3-digit</td><td>2-digit</td><td>2-digit</td><td>2-digit</td><td>2-digit</td></tr>
<tr><td>Caliper</td><td>0.2</td><td>0.05</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td></tr>
<tr><td>On support</td><td>90241</td><td>89979</td><td>90289</td><td>90557</td><td>142963</td><td>190251</td></tr>
<tr><td>Treatment group</td><td>787</td><td>525</td><td>835</td><td>873</td><td>1430</td><td>1677</td></tr>
<tr><td>Control group</td><td>787</td><td>525</td><td>835</td><td>873</td><td>1430</td><td>1677</td></tr>
<tr><td>Off support</td><td>425</td><td>687</td><td>377</td><td>523</td><td>390</td><td>453</td></tr>
<tr><td>Tangible fixed assets (in logs), 2004</td><td>6.4 | in</td><td>0.6 | in</td><td>−0.1 | in</td><td>−0.0 | in</td><td>0.3 | in</td><td>−0.4 | in</td></tr>
<tr><td>Tangible fixed assets (in logs), 2003</td><td>7.7 | in</td><td>1.4 | in</td><td>1.8 | in</td><td>0.3 | in</td><td>0.3 | in</td><td>2.5 | out</td></tr>
<tr><td>Tangible fixed assets (in logs), 2002</td><td>7.9 | in</td><td>1.2 | in</td><td>2.2 | in</td><td>1.2 | in</td><td>1.0 | in</td><td>2.8 | out</td></tr>
<tr><td>Total assets (in logs), 2004</td><td>11.0 | in</td><td>11.8 | in</td><td>4.5 | in</td><td>5.8 | in</td><td>4.5 | in</td><td>3.8 | in</td></tr>
<tr><td>Total assets (in logs), 2003</td><td>11.9 | in</td><td>12.8 | in</td><td>5.4 | in</td><td>6.3 | in</td><td>4.7 | in</td><td>4.3 | out</td></tr>
<tr><td>Total assets (in logs), 2002</td><td>13.3 | in</td><td>13.3 | in</td><td>6.6 | in</td><td>7.1 | in</td><td>5.4 | in</td><td>4.4 | out</td></tr>
<tr><td>Tangible fixed asset ratio, 2004</td><td>−7.6 | out</td><td>−26.3 | out</td><td>−10.1 | out</td><td>−13.4 | out</td><td>−7.9 | out</td><td>−10.4 | out</td></tr>
<tr><td>Tangible fixed asset ratio, 2003</td><td>−4.1 | out</td><td>−24.7 | out</td><td>−5.5 | out</td><td>−11.1 | out</td><td>−7.1 | out</td><td>−6.4 | out</td></tr>
<tr><td>Tangible fixed asset ratio, 2002</td><td>−5.5 | out</td><td>−25.5 | out</td><td>−6.2 | out</td><td>−10.5 | out</td><td>−7.8 | out</td><td>−6.1 | out</td></tr>
<tr><td>Operating revenue (in logs), 2004</td><td>13.1 | in</td><td>19.1 | in</td><td>6.6 | in</td><td>8.6 | in</td><td>6.4 | in</td><td>6.2 | in</td></tr>
<tr><td>Operating revenue (in logs), 2003</td><td>12.6 | in</td><td>19.6 | in</td><td>6.7 | in</td><td>8.2 | in</td><td>5.8 | in</td><td>6.5 | out</td></tr>
<tr><td>Operating revenue (in logs), 2002</td><td>13.3 | in</td><td>19.9 | in</td><td>6.6 | in</td><td>8.8 | in</td><td>6.2 | in</td><td>5.3 | out</td></tr>
<tr><td>Profit ratio, 2004, winsorized</td><td>−7.5 | in</td><td>−16.1 | in</td><td>−11.7 | in</td><td>−14.2 | in</td><td>−7.3 | in</td><td>1.3 | in</td></tr>
<tr><td>Profit ratio, 2003, winsorized</td><td>−12.5 | in</td><td>−15.2 | in</td><td>−15.2 | in</td><td>−17.6 | in</td><td>−7.1 | in</td><td>−9.0 | out</td></tr>
<tr><td>Profit ratio, 2002, winsorized</td><td>−7.6 | in</td><td>−15.6 | in</td><td>−14.1 | in</td><td>−15.7 | in</td><td>−6.7 | in</td><td>−1.0 | out</td></tr>
<tr><td>Investment ratio, 2004</td><td>−9.7 | in</td><td>−10.8 | in</td><td>−12.7 | in</td><td>−7.1 | in</td><td>−2.1 | in</td><td>−13.8 | out</td></tr>
<tr><td>Investment ratio, 2003</td><td>−6.0 | in</td><td>−12.0 | in</td><td>−7.7 | in</td><td>−8.5 | in</td><td>−3.3 | in</td><td>−12.6 | out</td></tr>
<tr><td>Date of incorporation</td><td>−6.8 | in</td><td>−14.1 | in</td><td>0.9 | in</td><td>−4.5 | in</td><td>−5.1 | in</td><td>−2.2 | in</td></tr>
</table>

Treatment groups include only firms known to have been active in both phases of the EU-ETS.

(out) indicates variables that were not part of the balancing process.

Corrections done in all samples: pre-balancing max value threshold, exclusion of firms with implausible data.

Significance levels: * p <0.10, ** p <0.05, * * * p <0.01

All samples based on 1-1 nearest neighbour matching, exact matching on country and sector.

A.3. Baseline Summary Statistics

Table 9: Summary Statistics (2004) - Baseline

	Before Balancing											
	Treated						Control					
Variable	Mean	Std. Dev.	Median	Min.	Max.	N	Mean	Std. Dev.	Median	Min.	Max.	N
Tangible fixed assets (in logs)	9.954	1.659	10.071	3.445	13.219	1915	5.980	1.873	5.897	1.722	13.187	324193
Total assets (in logs)	10.914	1.586	10.981	5.476	15.121	1915	7.908	1.440	7.771	2.746	15.224	324193
Tangible fixed asset ratio	0.469	0.238	0.462	0.000	0.966	1915	0.260	0.241	0.181	0.000	1.000	324193
Operating revenue (in logs)	10.766	1.658	10.845	4.179	14.309	1915	8.182	1.375	8.033	2.092	14.319	324193
Profit ratio	0.064	0.117	0.054	−2.475	0.546	1915	0.042	1.153	0.040	−328.916	3.043	324193
Investment ratio	0.049	0.117	0.023	−0.491	1.349	1915	0.037	0.121	0.006	−0.864	1.503	324193
Date of incorporation	1976.468	26.897	1987.000	1748.000	2004.000	1915	1986.957	13.890	1991.000	1383.000	2004.000	324193

	After Balancing											
	Treated						Control					
Variable	Mean	Std. Dev.	Median	Min.	Max.	N	Mean	Std. Dev.	Median	Min.	Max.	N
Tangible fixed assets (in logs)	9.407	1.574	9.502	3.445	13.011	1321	9.389	1.571	9.531	2.595	13.052	1321
Total assets (in logs)	10.473	1.492	10.470	5.476	15.121	1321	10.364	1.520	10.400	5.333	14.432	1321
Tangible fixed asset ratio	0.435	0.238	0.413	0.000	0.966	1321	0.449	0.227	0.429	0.005	0.992	1321
Operating revenue (in logs)	10.368	1.574	10.360	4.179	14.209	1321	10.307	1.616	10.331	4.421	14.189	1321
Profit ratio	0.063	0.122	0.053	−2.475	0.486	1321	0.056	0.129	0.047	−1.053	0.730	1321
Investment ratio	0.045	0.117	0.019	−0.491	1.349	1321	0.048	0.118	0.023	−0.824	0.997	1321
Date of incorporation	1976.980	25.531	1987.000	1753.000	2004.000	1321	1977.436	27.832	1988.000	1710.000	2003.000	1321