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

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Abstract: This study seeks to investigate 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 spectre of an erosion of European asset bases. Baseline results indicate that the EU ETS led to an on average increase of treated firms' asset bases of 12,1%. However, for a particular subgroup of MNEs, this increase is a mere 2.1%. For these companies, the EU ETS may have induced a shift in investment priorities.

Keywords: EU ETS; cap-and-trade; carbon leakage; multinational corporation
JEL Classification: F23, H23, Q54, Q58, C21

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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. An important starting point of this paper is that during the first two trading periods (2005-2012), the time frame of our analysis, the European carbon policy was not met by any comparable initiatives in other world regions. Even though a number of programs were started subsequently to the EU ETS, these regionally or temporally confined efforts did not alter its unilateral character. They were substantially limited in terms of stringency and scope (e.g. country, sectors and emissions coverage) and in several cases even discontinued. With the start of trading in the EU, the share of global emissions covered by a carbon price jumped from less than 1% to around 5% (Worldbank et al. 2017). It remained largely the same until 2012. 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 (DiD) approach that exploits 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 at the installation level, 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 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 11,2%. In the subsample for the manufacturing sector, which is at the center of fears with respect to industrial relocation, this overall effect reaches a size of 12.1%. Notably, we find that EU ETS-firms which are part of a global MNE with a functional link do not behave different than the remainder of the sample. This is important since these companies not only could relocate capacities to non-regulated regions at relatively low costs, but also account for an important share of emissions under the EU ETS. However, we find a markedly different reaction for those treated firms that belong to a global MNE

without a 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 2.1%, i.e. 10.0% below the remainder of the treatment group.

Assessing the first two trading phases separately reveals that both effects, the overall treatment effect and the differential effect for firms of the manufacturing sector that belong to global MNEs without functional link, are more pronounced in phase II.

The overall effect of broad asset increases proves to be highly robust when we put more weight on internal validity and tighten the sample restrictions. At the same time, it also extends to larger, less restrictive samples that cover up to 54% of total emissions regulated and are similar to the matched raw data in terms of country spread. The same holds true for the interaction effect for global MNEs without a functional link in the manufacturing sector. It is robust and present in samples that comprise up to 39.4% of total regulated emissions from that sector.

Our study contributes to ex-post evaluations of the EU ETS in general by delivering a very comprehensive cross-country analysis and to the discussion on industrial relocation in particular by providing a new perspective on asset erosion in Europe. We find robust evidence that contradicts the idea of a creeping erosion of European asset bases as a consequence of carbon policy. The EU ETS appears to have increased the asset bases in Europe, even though for a subgroup of MNEs the effect is less sizeable and could indicate some shift in their regional investment priorities.

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 2014 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% to 30% (Böhringer, Balistreri, and Rutherford, 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 2017), nor through a rise in Foreign Direct Investment, analyzed for Italian MNEs by Borghesi, Franco, and Marin (2018) and for German MNEs by Koch and Basse Mama (2016). The study by Dechezleprêtre, Gennaioli, Martin, and Muûls (2015) is so far the investigation that most closely shares our conceptual emphasis on potential intra-firm shifts of emissions. 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 Obern-dorfer 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 providing credible estimates of policy impacts 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 sim-ilar 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 estimates based on country specific administrative data (Petrick and Wagner 2014 and Wagner et al. 2014) or commercial databases (Marin, Pellegrini, and Marino 2017).

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 empir-ical 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 CO_2-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

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[1]In the first trading period (2005-2007), the fine was 40€ per ton CO_2-equivalent. In the second period (2008-2012), the fine was 100€.

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] 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] In the third phase of the EU ETS (2013-2020), auctioning has become the default mode of allowance allocation. For this phase, the share of auctioned allowances is estimated to be 57% (European Union, 2018).

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

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[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 joined the scheme.

[5] Calculations based on ICE Futures Europe EU Allowance data. In December 2012, the average EUA future price was 7.20 Euros. During the last year of the first trading phase (2007) the allowance price effectively dropped to zero and rebounded temporarily in the beginning of the second phase (mid-2008) to almost 30 Euros.

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.

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 technology)

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[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.

[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).

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 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 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 foundations of our empirical approach are grounded in the extensive literature on the economics of multinational production. Studies have stressed that geographical diversification is not only a means to improve access to foreign markets (Johanson and Vahlne, 1977; Dunning, 1988; Dunning and Lundan, 2008), but to increase operational and strategic flexibility with respect to policy-induced production shocks. De Meza and van der Ploeg (1987) argue in an important theoretical contribution that the up-front establishment of global subsidiaries is particularly important in industries with long investment horizons. Once a sufficiently high initial investment has been made, follow-up investments can be implemented with lower costs as a way to react to policy shocks in

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[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 (1995), 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."

[9]Cowie and Heathcott (2003) illustrates the changes in the US manufacturing sector in the 1980s.

certain world regions. Multinational companies have been shown empirically to rely on these options in the context of changes in the exchange rate, labor costs or economic crises and regulatory uncertainty (Rangan, 1998; Beiderbos et al., 2009; Chung et al., 2010; Fisch and Zschoche, 2012).

These insights are of high relevance for our specific policy context: First, investments into energy intensive assets as well as carbon policies itself have a long time horizon and are thus inherently uncertain. Second, the EU ETS introduced a shock to the production structure of companies that needed to adapt. Third, in our global firm database, we are able to distinguish two types of investment stages abroad: non-EU subsidiaries that already operate in the same sector as their respective sibling within the EU ETS (*with functional link*) and subsidiaries of multinational business groups that do not operate in the same sector but are still outside of the regulatory area (*without functional link*). Both types of subsidiaries provide an MNE with real options to circumvent the policy if this should become necessary: While MNEs with an established functional link are already in the position to shift capacity quite easily (e.g. between two sites that produce steel) and at comparatively low costs, MNEs without a functional link have at least secured a foothold in a foreign market.

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 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

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[10]To ensure a high data quality we use unconsolidated financial information from local registry filings.

[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.

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 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 corre-

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[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 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.

sponds 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 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 bottom 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

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[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.

between already existing firms.

<div align="center">[Figure 1 and 2 about here]</div>

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 impact of the EU ETS on treated firms asset bases with a special focus on the differential behaviour of firms pertaining to Global MNEs.[17] 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 effect of the EU ETS if the distributions

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[17]Note that while our dataset is comprehensive in terms of information on ownership, country and sector affiliation, and European assets, it does not allow us to track the global asset structure of a business group.

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 effect of the European carbon market (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 effect of 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 impact of the carbon policy.

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.[18] For instance, a steel plant will be covered by the EU ETS if its

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[18]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.

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.[19]

Note that our dataset does not allow us to observe this production capacity, neither at the installation nor at the firm level. Thus, we cannot determine if a specific installation covered by the EU ETS is similar in size compared to an installation that is not regulated. However, 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. 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

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

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 or underestimate a potential treatment effect by sampling (potentially) affected firms into a control group. If business groups increased their assets for both ETS and non-ETS subsidiaries in response to the policy, we would underestimate the effect. If they reallocated capacities from non-regulated to regulated firms, we would overestimate it.

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.[20] 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).[21] 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 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,

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[20]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.

[21]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.

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. 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. We focus on the main sector of activity to account for differences in the primary operational structure of firms, e.g. with respect to their production technology. Note that most secondary activities share the same 2-digit sector of the main activity and differ only with respect to the 4-digit level. It is therefore likely that matching on primary activities will balance out secondary activities as well.

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 inde-

pendent of scale.[22] The results of the balancing process for different samples are reported in Appendix A.3, Table 10, column 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.[23] 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.[24] 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 about here**]

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 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.[25] 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

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[22]It is defined as

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

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).

[23]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).

[24]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.2.

[25]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.

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.

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 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.

[**Figure 4 about here**]

4.2. Stage II: Estimation of treatment effects

In the second stage of our analysis, we seek to obtain estimates for the average treatment effect on the treated (ATET), i.e. the average effect of the EU ETS on regulated firms' asset bases, and for the differentiated treatment interaction effects of two specific firm types with respect to their international business group structure. While our general approach of combining matching with DiD follows Heckman et al. (1997) as summarized in Blundell and Dias (2009), our notation for DiD follows Lechner (2010). Capital letters denote random variables and small letters denote specific realizations. The usual

definition of the ATET reads as follows (see Lechner 2010, 175):

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

In Equation 1, D is the binary treatment variable ($D \in 0, 1$) that, in our context, denotes whether a firm is regulated under the ETS ($D = 1$) or not ($D = 0$). In the simplest case with only two time periods ($t \in 0, 1$), period zero hence indicates a time period before the treatment (pre-treatment period) and period one indicates a time period after the treatment started (post-treatment period). The realized values of observed covariates in X are denoted by x. Hence, specific effects $\theta_t(x)$ for different subpopulations of the treated firms (e.g. from different sectors regulated by the EU ETS) are defined by the value of X being x.

Y_t^d denotes the potential outcome, i.e. the level of tangible fixed assets that would be realized for a specific value of D in a specific period t. Thus, $Y_{1,i}^1$ corresponds to the outcome of a specific firm i in the post-treatment period 1 if it was regulated by the EU ETS ($D = 1$). Since we cannot observe post-treatment outcomes for the treated firms if they had not been treated, we have to establish a precise and tenable estimate for the counterfactual $E\left[Y_{1,i}^0 | D = 1\right]$ for each treated firm. With these estimates at hand, the ATET can be computed as a difference in two differences of respective period averages for the outcome variable as follows (see Lechner 2010, 183):

$$
\begin{aligned}
ATET_t &= \left[E(Y_1 | X = x, D = 1) - E(Y_0 | X = x, D = 1)\right] \\
&\quad - \left[E(Y_1 | X = x, D = 0) - E(Y_0 | X = x, D = 0)\right]
\end{aligned}
\tag{2}
$$

To obtain a credible estimate for the level of tangible fixed assets that treated firms would have had in the absence of the EU ETS, a set of identifying assumptions must be fulfilled.

The key assumption of the DiD-approach, as outlined by Lechner (2010), is the *Common Trend Assumption*. The assumption implies that, had the treated firms not been

subject to the treatment, both subpopulations defined by $D = 1$ and $D = 0$ would have experienced the same time trends conditional on the variables in 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 (spillover effects) between members of the two groups. Notably in the context of a firm-level analysis, this poses two challenges: Firstly, the more accurate the matching of treatment and control group is executed in terms of country and sector affiliation, the more likely it becomes that matched firms are competitors on the same market. We address this issue to some extent by balancing out the sector-country distributions using the broader NACE 2-digit sector classification.[26] Secondly, if firms are connected in business groups via ownership links, direct spill-over effects could occur for example as a result of higher-level management decisions. For a given treated firm, this would render all firms that are part of the same business group 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 the covariates in X are not influenced by the treatment.

We also assume the *Absence of Anticipation Effects*. This is a challenge given our specific policy context. Under the EU ETS, firms may have had an incentive to adjust their asset bases already in anticipation, i.e. before the legal coming into effect of the policy in January 2005. The concern is that firms could have adjusted their asset bases prior to 2005 in an attempt to either circumvent the policy or, on the contrary, to select themselves into the treatment to obtain benefits from the free allocation of allowances. If some firms chose to select themselves into the EU ETS by increasing their asset base pre-2005, our approach may overestimate the ATET. Vice versa, if firms chose to cir-

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[26]In one of our robustness checks, we put more emphasis on sector-wise similarities and use the more detailed NACE 3-digit classification.

cumvent the policy by decreasing their assets, we would not capture the entire ATET, but underestimate it. Note that our pre-treatment data (2002-2004) does not include information before early discussions on the possible introduction of a European carbon market started in 2000. However, given considerable uncertainty during the lengthy and open negotiation process on the policy's implementation, the degree and impact of self-selection may have been limited. In the robustness section 5.3, we discuss the possibility of anticipation effects in more detail.

To implement the DiD identification strategy and estimate not only the overall treatment effect but also the treatment interaction effects for specific firm types, we apply the common linear regression model to our balanced sample. Since we use one-to-one nearest neighbor matching without replacement, there are no weights used in the estimation of our baseline results. Our econometric estimation equation that integrates the DiD framework delineated in equation 2 into a linear regression model reads as follows:

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

Here y_{it} denotes the level of tangible fixed assets of a given company i in year t (in logs), α is a constant, α_i is the firm-level fixed effect, $treat_{it}$ is the interaction of the firm-specific treatment group indicator variable ets_i and the time-specific period indicator variable $period_t$, $year_t$ 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 consists only of time-related effects (unreported) and several interaction terms. In particular, the term $treat_{it}$ captures the overall treatment effect of the EU ETS while the terms $[mne\_link_{it} * treat_{it}]$ and $[mne\_nolink_{it} * treat_{it}]$ capture the two differentiated treatment effects for firms that are part of a multinational business group *with*

link or *without link*. The respective size of the three treatment effects is given by the estimated values of the coefficients δ, ϕ_2 and φ_2. We follow the insights in Abadie (2005) and Abadie and Spiess (2016) and cluster the standard errors at the level of the matches in our setting, i.e. the country-sector 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.

[**Table 1** about here]

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 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. In contrast, the coefficient for multinationals without a functional link corresponds to a 9.4% decrease in tangible fixed assets relative to the remainder of the sample. It appears that most treated firms increased their tangible fixed asset bases by a sizeable 10.1% to 11.2%. This finding is plausible given that the sample contains firms from both the energy and the manufacturing sectors. Note that firms from the energy sector are unlikely to experience asset erosion due to their low exposure to international competition.

We therefore proceed with the analysis for sector specific samples with a particular focus on the manufacturing sector which is at the center of concerns for industrial relocation.

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 estimation of treatment effects, 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.3, Table 10. 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.[27]

[**Table 2** about here]

Secondly, we compare the estimation results for these subsamples with our baseline sample. This is reported in Table 2. For all of the three subsamples, the ETS treatment effect remains highly significant and at a sizeable magnitude.[28] The DiD estimates point towards a positive effect, i.e. an increase of asset bases ranging from 12.1% to 21.6%.

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

[28]Manufacturing and CLL-only samples: Significant at the one percent level. Energy: Significant at the five percent level.

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 five percent level (baseline: significant at the five percent level), the effect is insignificant for the CLL-only sample and the energy firms.

Overall, the results point towards considerable asset increases across all (sub-)sectors. We also find evidence for a different behavior of multinational companies with no functional link that manifests itself in the manufacturing sector.

For this sector, 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 2.0%. This overall effect is statistically significant at the one percent level. For energy and/or trade intensive firms (CLL-only sample) the effect of the EU ETS on tangible fixed asset bases 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.

In unreported analyses, we employ a dummy variable for manufacturing firms that are either emission-intensive and/or trade-intensive in the all industries sample. The overall treatment effect is in a range of a 9.0% to 10.1% increase of tangible fixed assets, i.e. similar to the baseline results. For the subgroup, we even find evidence for an overall decrease of tangible fixed assets of 3.4%, i.e. signs of moderate asset erosion. However, the effect is just significant at the ten percent level. Due to these challenges for the two smaller subsamples (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.

[Table 3 about here]

Table 3 shows the manufacturing baseline 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 5.4% to 6.4%. In phase II, the treatment effect is considerably higher, ranging from 14.9% to 16.4%. Estimates for phase II are significant at the one percent level, whereas estimates for phase I are significant at the five percent 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 ETS than other firms. In phase II, the interaction term is significant at the five percent level and corresponds to a 13.9% decrease in tangible fixed assets relative to the rest of the sample. Hence, the aggregate phase II treatment effect for these firms, i.e. the sum of treatment effect and MNE-specific interaction effect, corresponds to an increase in asset bases by only 2.3% (16.2% for other treated firms).[29] For phase I, the estimate for the interaction term is statistically insignificant, which may suggest that global MNEs still behaved similar to other companies during phase I.

5.3. Robustness

One challenge to the unconfoundedness assumption is the potential presence of unobserved confounders. We assess the plausibility of imbalances for potential confounders that did not enter our design stage.

First, Table 11 in Appendix A.3 reports balancing results for different manufacturing samples, both for financial covariates that entered the design stage and for additional variables that were not part of the balancing process. The simple balancing sample in column 6 requires balance only on 2004 firm characteristics. Yet, it also to firms in both groups being very similar for their respective covariates in 2003 and 2002.[30] This finding highlights that achieving covariate balance for a given year is conceivable to produce

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[29]The 2.3% overall effect of firms that pertain to a global MNE without functional link is significant at the one percent level.

[30]For instance, we achieve a very good balance for tangible fixed assets in 2003 and 2002 (standardized differences 2.5 and 2.8 respectively), although our pre-treatment outcome only entered the design stage for the year 2004.

balance in these covariates for other pre-treatment years that we do not observe, i.e. years previous to 2002.

Second, we inspected the balance for employment, a covariate that never entered the design stage. Distributions are actually very similar between the two matched groups.[31] 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.

Third, we explore potential differences in business structure and sector affiliation. 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 functional link).

[**Table 4 about here**]

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 one percent 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

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

assets by 2.6%. The latter finding points towards an erosion of the asset bases of theses companies owing to 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.[32] The results generally support our previous findings, although we do observe some modest differences.[33] 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 the plausibility of our assumption of stability of unit treatment values (SUTVA), i.e. the absence of spillover effects between treatment and control group. Our research design does not allow companies that are connected to treated firms via ownership links to enter the control group, thus preventing any spillovers within business groups. In addition, we conduct our analysis at the firm level and thus rule out the possibility of intra-firm spillovers between installations (Petrick and Wagner, 2014).

However, non EU-ETS firms may still respond to the policy either directly or indirectly, e.g. if they engage in competition with EU-ETS firms. While it is not possible to empirically test the full extent of the SUTVA, we can test an institutional setting under which a violation of it may take place (Fowlie, Holland, and Mansur, 2012). If non-regulated firms responded to the policy e.g. through interaction with regulated firms, then one would expect a group of non-ETS firms which have been less exposed to the EU ETS to respond to a lesser degree (Calel and Dechezleprêtre, 2016).

We therefore match a new group of control firms to the treated firms. This new control group is entirely composed of firms from countries that did not join the EU ETS in 2005: Croatia, Norway, Bulgaria and Romania. Note that given the smaller pool of potential control firms, we can only perform the test for samples that are less restrictive in the

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

[33]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.

design stage.[34]

<center>[**Tables 6 and 7 about here**]</center>

Tables 6 and 7 show for two manufacturing samples[35] that estimation results do not differ in any important way from our main results. In the most sizeable sample ("Simple balancing"), magnitudes of coefficients are only slightly more pronounced for the overall effect and less pronounced for the interaction effect of MNEs with no functional link. The only more apparent divergence is that the interaction effect is no longer significant. However, the interaction effect remains significant in the second largest manufacturing sample (see Table 7).

Overall, the results of our "late joiner test" do not lend support to the idea that our estimate of the ATET might be an artifact of control firms reacting to the policy. If anything, the results suggest that we might slightly underestimate the policy's general impact and slightly overestimate its specific impact on MNEs without a functional link. However, due to between-country differences for which these re-matched estimates cannot control, we have to be cautious with this interpretation. Neither of the re-matched estimates differs significantly from our original estimates. Hence, they do not represent a substantive challenge to our findings.

In section 4.2, we also highlighted the potential challenge of announcement effects that may lead us to either over- or underestimate the average treatment effect of the EU ETS. Note that our pre-treatment data do not include years before very early negotiations on a common European carbon policy began. Hence, announcement effects could lead us to either under- or overestimate the treatment effect.

It is an open question whether or not firms had a clear incentive to pursue an active strategy and the time necessary to implement it. While at the beginning of the 2000s firms should have had certainty of the imminence of some sort of carbon policy, there

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[34]We report results only for samples that are based on matching with replacement (see section 5.4). Samples based on matching without replacement are qualitatively identical. However, they are less informative due to considerable covariate imbalances. These stem from the fact that the small number of available comparison firms from the four late joiner countries is used up rather quickly in a process of matching without replacement.

[35]See descriptives and balancing information in Table 13, columns 3 and 4, in section A.3 of the appendix.

<center>31</center>

was considerable uncertainty with respect to the technical implementation, in particular policy scope and stringency. In the negotiations prior to the introduction of the EU ETS, two important features of the European carbon market became clear rather late: the prime mode of allowance allocation (for free, via grandfathering, or with monetary costs, via auctioning) and, to some degree, the sectors and types of installations that were to be included (cf. Convery, 2009). For instance, only shortly before the coming into effect of the EU ETS, member states failed to secure a right to exempt specific installations or entire sectors. Likewise, the possibility to delay the inclusion, by national discretion, of certain industries (e.g. production of aluminium and chemicals) was also ruled out at short notice before the launch of the EU ETS. These industries happen to be of particular relevance for our research question on industrial relocation. Contributing to the regulatory uncertainty, alternative instruments such as command-and-control or a carbon tax were simultaneously discussed in case the introduction of a carbon market failed.

Hence, it seems plausible that not the introduction of a carbon policy per se, but its potential costs or benefits may have been somewhat unclear to firms. While this issue cannot be resolved empirically in our study, it raises questions on the firms' incentive to actively prepare for the introduction of the policy.

Lastly, we discuss the relevance of our novel dataset in properly identifying the effects on treated firms that are part of multinational business groups. For this purpose, we compare results based on our dynamically derived ownership structures with results from samples that use static definitions of MNEs. Note that in many firm datasets information on ownership is very limited. As a rule, information on the affiliation of an individual firm to a multinational network is only provided for one specific point in time, usually the last available (i.e.: most recent) year.

Yet, this standard raises severe problems in terms of data accuracy. Consider that ownership information from year 2012 is unlikely to be a reliable predictor of firm structures in the years before, i.e. whether in the past, a company was part of an MNE or not, and, if so, in which type of network. In fact, changes in ownership over time are very frequent

in our panel data that cover the years 2002-2012. At the same time, older information for one particular year is even more likely to suffer from poor data quality as ORBIS is constantly being updated and extended, mostly at the current edge but at times even for earlier years.

Hence, using static ownership information likely introduces substantial measurement error and impedes a proper identification. This could also lead to imbalances between firms treated by the EU ETS versus untreated firms, especially if data quality differs between the two groups.

We test for the relevance of precise (i.e. dynamic) ownership identification by first utilizing relatively old ownership information from year 2004 and second relatively new information from year 2012. In both cases, we assume this information to be constant for all years, overwriting the remainder of years with the respective information. We then re-estimate our model with the respective static ownership information.

Our results for using static ownership information either from 2012 or 2004 do confirm the overall treatment effect, but the differential effect for the subgroup of treated MNE firms without functional link is now insignificant and cannot be identified (see Table 5. This finding demonstrates the importance of using dynamic ownership information to properly identify treatment effects on firms that are part of multinational business groups.

[**Table 5 about here**]

5.4. External validity

The fundamental idea of the ingenious identification strategy that was pioneered by Calel and Dechezleprêtre (2016) and subsequently applied by Petrick and Wagner (2014); Wagner et al. (2014) and Marin et al. (2017) entails one inevitable drawback: the larger a treated EU ETS firm is with respect to the size of its installations, the less likely it becomes that a comparable non-ETS firm from the same country and sector can be identified and matched. When matching is done without replacement, these somewhat exceptional control firms are used up rather quickly. As we reported in section 4.1, 594 treated firms had to be discarded in our original design stage for lack of a suitable

matching partner. Hence, to increase sample size and the share of covered emissions, we tried the remedy of matching with replacement.

In a first step, except for using a same control firm multiple times as long as it is the best possible match for a given treated firm, we did not change any other parameter of the matching algorithm.[36] In a stepwise manner, further restrictions of the original balancing process were relaxed, with respect to (a) the importance of accounting for outliers, (b) non-surviving firms (panel attrition) and connected firms, and (c) balancing on potential confounders in all pre-2005 years.[37]

The ramifications of matching with replacement for four different sample types "Baseline", "With large firms"[38], "Without restrictions"[39], and "Simple balancing"[40] are documented in Table 12 for all sectors and in Table 13 for the manufacturing sector.

[**Tables 12 and 13 about here**]

Already the first column of Table 12 proves that matching with replacement is very effective in increasing the sample size: the number of matched treated firms increases from 1321 in the benchmark sample (see Table 10 to 1833, i.e. by almost 39%. The share of matched emissions increases even by a factor of 2.5, from 4.4% two 11.1%. The lifting of other restrictions from the original design stage further adds to sample size and share of covered emissions. In column 4 of Table 12, the number of treated firms reaches a maximum of 3339, representing more than half of all registered EU ETS emissions during

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[36]We still matched nearest neighbors one-to-one using a caliper of 0.2 to prohibit matching of firms that differ too much in their respective propensity scores. As before, we enforced matching within exact country-sector bins. This exact matching defines the appropriate clustering of standard errors in the case of matching with replacement: a given control firm might now be used multiple times as best available match for different treated firms, but all these pairings will happen inside of the same country-sector bin. The level of these country-sector cells is therefore also the appropriate level for the clustering of standard errors.

[37]We also experimented with even more parsimonious configurations of the matching stage, using only one (tangible fixed assets) or two variables (tangible fixed assets and total assets) as regressors in the respective propensity score estimation. While the quality of the balancing achieved by this "micro matching" approach was quite good for some samples, the realized gains in sample size were negligible. Likewise, including as treated any firm that at any point was part of the ETS, rather than dropping those firms that do not have verified emissions in both trading phases, does not yield a relevant gain in sample size or matched emissions.

[38]Inclusion of the 0.1% bottom and top firms with respect to the variables stated in footnote 21

[39]Inclusion of firms that are connected to the treatment group and of firms with missing asset data

[40]Use of a simplified matching procedure that employs fewer matching variables and is restricted on year 2004 values

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the first two trading periods.

The substantial improvement in external validity that is achieved by matching with replacement is illustrated by figure 7. The left panel plots the lognormal distribution of firms' verified emissons for the baseline sample without replacement, the right panel for the sample based on matching with replacement and simple balancing (column 4 of Table 12).[41]

[**Figure 7 about here**]

Figure 7 illustrates that the increase in the number of matched firms is balanced across the spectrum of emissions. The increase in the share of matched emissions, however, is sensitive to the right tail of the distribution: Whereas the baseline sample includes only a small number of matched ETS firms with very large verified emissions, the sample with replacement includes considerably more large emitters. Although the mere number of these additionally matched ETS firms is comparatively small, their respective emission share is substantial.

At first sight, the gain in sample size comes with a certain price in terms of balancing quality. In particular, the standardized differences for the key variables "Tangible fixed assets" and "Total assets" are now above the lower threshold value for acceptable bias of ten percent for all pre-treatment years. Though, they are still significantly below the higher threshold of 25% that is regarded as a still acceptable maximum in parts of the applied econometrics literature (see Garrido et al., 2014, p. 1708). However, this potential problem of covariate imbalance vanishes when further sample restrictions are lifted, as depicted in columns 2 to 4 of Table 12: In columns 3 and 4, the balance diagnostics for most variables are below the lower acceptance threshold of ten percent or exceed it only slightly, with the highest value (11%) for total assets in year 2002, being a variable that was not included in the simplified balancing process. Overall, the switch to matching with replacement allows for a substantial increase of external validity in terms of ETS firms included and matched emissions. In addition, this gain does not cause a sacrifice

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[41]The blue bars represent all ET firms before matching and are identical in both panels. The red bars show the distribution for the subset of ETS firms that were successfully matched and hence entered the treatment group of the subsequent DiD estimations.

in terms of internal validity since a sufficient quality of the covariate balancing can still be achieved.

The DiD estimation results for the overall ETS effects on the basis of the two largest samples that were generated by matching with replacement are presented in tables 8 and 9 for all sectors and the manufacturing sector. These results corroborate our findings from the baseline setting: The ETS treatment effect for the all sector analysis is significant at the one percent level and consistent in size across the three different specifications in table 8 whereas the MNE effect and both MNE interaction effects are not significant. In contrast, column 3 of table 9 exhibits a negative interaction effect of 6.7% for treated firms of the type "Global MNE without functional link".[42] The aggregate effect for firms that belong to a global business group without a functional link amounts to 6.9% and is statistically significant at the one percent level.

[**Tables 8 and 9 about here**]

Overall, the use of matching with replacement allowed us to substantially improve the strength and relevance of both key results from our empirical investigation of ETS impacts on the asset bases of regulated firms. The positive overall effect of the ETS is highly significant, statistically and economically, across all relevant samples. Contrary to the spectre of asset erosion and creeping deindustrialization, we find that the EU ETS is associated with a growth of the asset bases of treated firms compared to the matched control groups.

The results for the manufacturing sector highlight the relevance of taking into account the business group structure of regulated firms. The differentiated effect for firms that belong to the category of "Global MNE without functional link" suggests that a specific group of MNEs could have shifted their regional investment priorities in response to the EU ETS, possibly to set up an "exit option" abroad.

We also explore the geographical spread across countries and compare each country's share of the total in-sample firm emissions with the respective value in the raw data

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[42]The results for all other, intermediate sample configurations of matching with replacement are available from the authors upon request. With respect to coefficient sizes and significance levels, these results are qualitatively in line with the results for the samples with replacement discussed above.

sample, i.e. the pool of active regulated companies out of the matched 96% of firms under the EU ETS.

In our most comprehensive samples with replacement[43] all major European economies are close to their respective raw data shares with only some minor deviations (see Table 15 for all industries and Table 16 in section A.5 of the appendix). Although our results might not be entirely representative of each individual economy, they are certainly sufficiently representative of the EU ETS as a whole. Thus, it appears unlikely that our effects are driven by a small number of overrepresented countries.

The only exception appears to be Italy, where the share of total emissions is 10.01% in the raw data and 15.13% in the final sample (corresponding values for manufacturing: 10.47% and 16.00%). With respect to smaller economies, the only exception might be Belgium, whose share increased from 2.58% in the raw sample to 4.38% in the final sample (corresponding values for manufacturing: 4.75% and 8.71% percent).

We test the sensitivity of our results to overrepresented countries by excluding them from the analysis. In the results for all resulting samples, the overall treatment effect remains virtually identical in terms of magnitude and significance level. For the interaction effect of MNEs with no functional link, the effect also remains robust, except for the most sizeable manufacturing sample. Despite this, the effect is still robust in a sample that corresponds to 17.5% of total regulated manufacturing emissions vs. 39.4% in the largest manufacturing sample (compare column 2 vs. column 4 of Table 13). Note that for this sample, the individual shares in raw and in-sample data are similar for most countries except for Italy and Belgium (see Table 17 in section A.5 of the appendix.) Hence, it appears unlikely that these countries would drive the interaction effect.

6. Discussion

The EU ETS is the largest cap-and-trade program in the world. Negative competitiveness impacts on regulated businesses have been discussed since its inception. Most notably, the concern is widespread that carbon leakage might occur through relocation decisions

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[43]See column 4 of Table 12 for all industries and column 4 of Table 13 for manufacturing.

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.

Matched Difference-in-Differences estimates provide robust evidence that casts severe doubt on the spectre 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 in the range of 10.1% to 11.2%. This finding complements empirical evidence on the impacts 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 effffect 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. (2018) 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. For the majority of companies we detect no signs of asset erosion but, on the contrary, comparatively substantial asset in-

creases. 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 thus 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.

Drawing from insights of the literature on multinational production under policy uncertainty, we distinguish between two structural features of multinational business groups that help these groups to alleviate relocation costs and provide them with the option to circumvent the policy if necessary: the ownership of at least one non-EU subsidiary that already operates in the same sector as their respective EU ETS-sibling (a so called functional link) or of at least one subsidiary operating not in the same sector but still outside of the regulatory area (no functional link).

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%. This company type accounted for 15.3% of manufacturing emissions under the EU ETS in 2012. 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 both effects, the positive overall treatment effect and the differential effect for treated manufacturing firms that belong to business groups of the category "Global MNE without link", can be extended to much more sizeable samples that result from changes applied during the design stage, i.e. matching with replacement and lifting of other sample restrictions. Our findings hence corroborate insights provided by Koch and Basse Mama (2016) and Borghesi et al. (2018), which show that, while the large majority of firms does not show a behaviour that is suggestive of industrial relocation, 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 that displays a differentiated effect, i.e. treated MNEs without functional link, does not correspond to an important, although not entirely negligible, 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. Industrial associations in Europe have already voiced concerns that an increased rigidity risks to undermine their firm's competitiveness. A recent simulation study by Perino and Willner (2017) on projected price impacts of the new rules for Phase 4 of the EU ETS (2021-2030) finds only very modest effects of the tightening of the cap. On the other hand, the ongoing revision of the carbon leakage list criteria might increase the share of companies in the manufacturing sector that have to pay for auctioned allowances instead of receiving them for free. Hence, the precise impact of the EU ETS on the European asset base of regulated firms will continue to be an important empirical question in coming decades.

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 until now, 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.

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A. Appendix

A.1. Result tables

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 match level.

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

Table 2: 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 match level.

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

Table 3: ETS impact by trading phase, manufacturing sector

	(1)	(2)	(3)
ETS Phase I treatment	0.054**	0.064**	0.060**
Global MNE and treated (I)		−0.038	
Global MNE without functional link and treated (I)			−0.043
Global MNE with functional link and treated (I)			−0.007
ETS Phase II treatment	0.149***	0.164***	0.162***
Global MNE and treated (II)		−0.047	
Global MNE without functional link and treated (II)			−0.139**
Global MNE with functional link and treated (II)			0.030
Firms (T+C)	1670	1670	1670

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

Standard errors are clustered on the country-sector level.

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

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 match level.

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

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 match level.

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

Table 6: Late joiner test, manufacturing, m. w. replacement, simple balancing

	(1)	(2)	(3)
ETS treatment effect	0.139**	0.148**	0.148**
Global MNE and treated		−0.023	
Global MNE without functional link and treated			−0.055
Global MNE with functional link and treated			−0.005
Firms (T+C)	2609	2609	2609

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

Standard errors are clustered on the country-sector level.

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

Table 7: Late joiner test, manufacturing, m. w. replacement, no restrictions

	(1)	(2)	(3)
ETS treatment effect	0.258***	0.265***	0.265***
Global MNE and treated		−0.018	
Global MNE without functional link and treated			−0.063**
Global MNE with functional link and treated			0.009
Firms (T+C)	2208	2208	2208

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

Standard errors are clustered on the country-sector level.

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

Table 8: ETS effects for all sectors, matching with replacement, simple balancing

	(1)	(2)	(3)
ETS treatment effect	0.115***	0.121***	0.121***
Global MNE and treated		−0.018	
Global MNE without functional link and treated			−0.030
Global MNE with functional link and treated			−0.010
Firms (T+C)	5808	5808	5808

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

Standard errors are clustered on the country-sector level.

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

Table 9: ETS effects for manufacturing, matching with replacement, simple balancing

	(1)	(2)	(3)
ETS treatment effect	0.126***	0.136***	0.136***
Global MNE and treated		−0.023	
Global MNE without functional link and treated			−0.067**
Global MNE with functional link and treated			−0.000
Firms (T+C)	3505	3505	3505

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

Standard errors are clustered on the country-sector level.

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

A.2. Figures
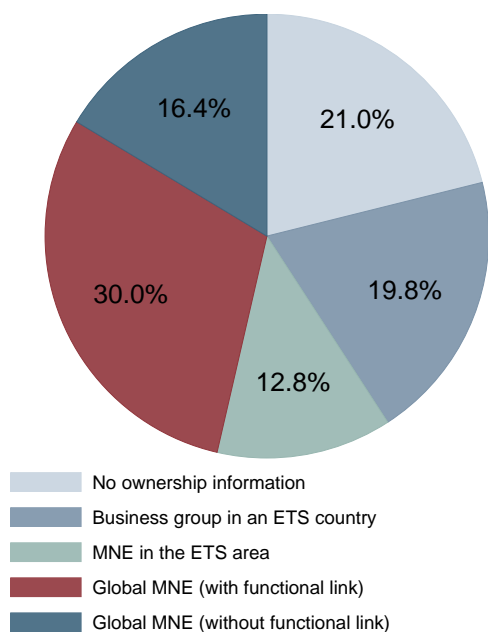
Figure 1: Firms by firm type in manufacturing, 2012

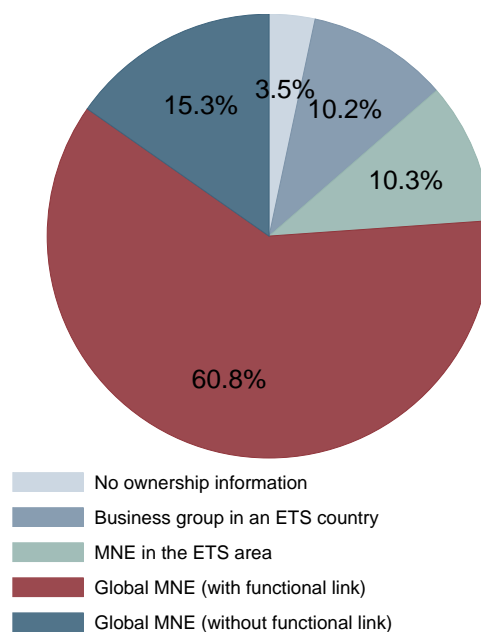**Figure 2:** Verified emissions by firm type in manufacturing, 2012

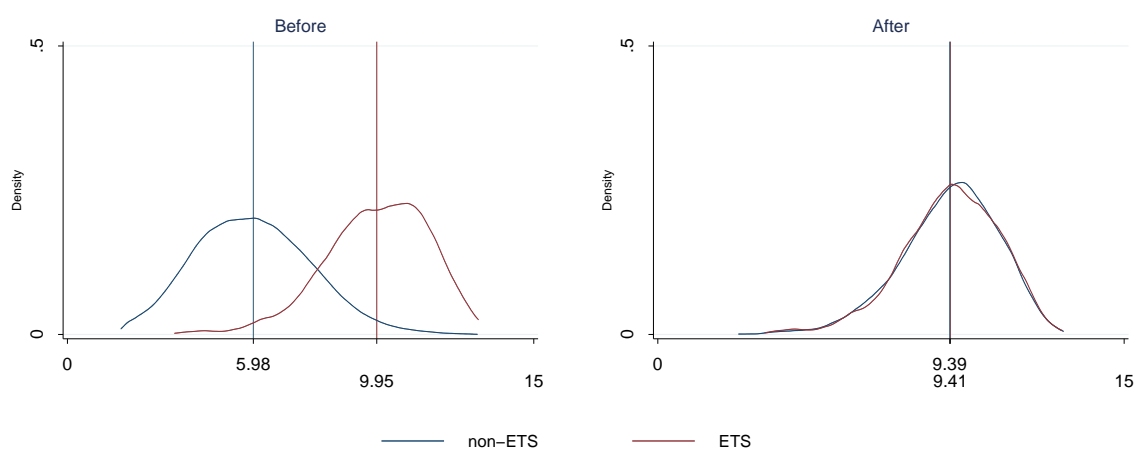**Figure 3:** Tangible fixed assets (in logs) in 2004 before and after balancing

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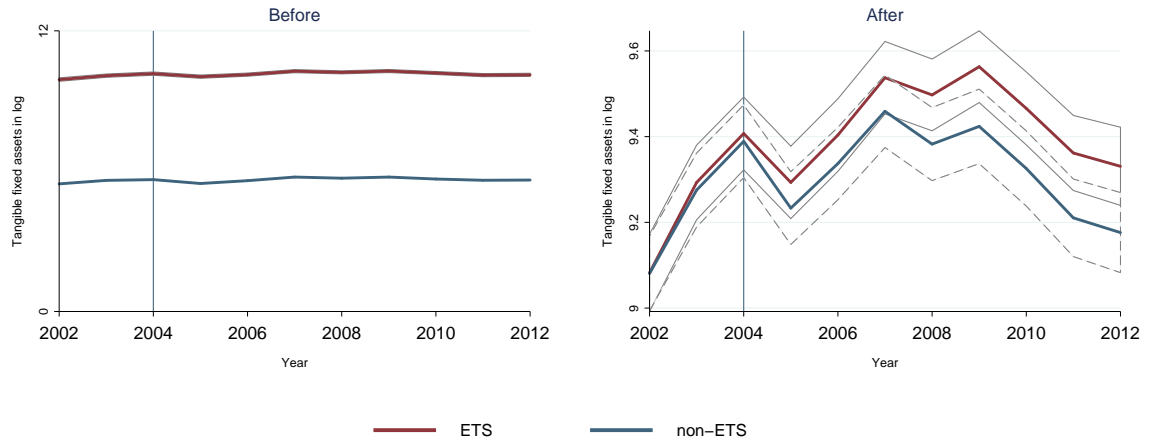

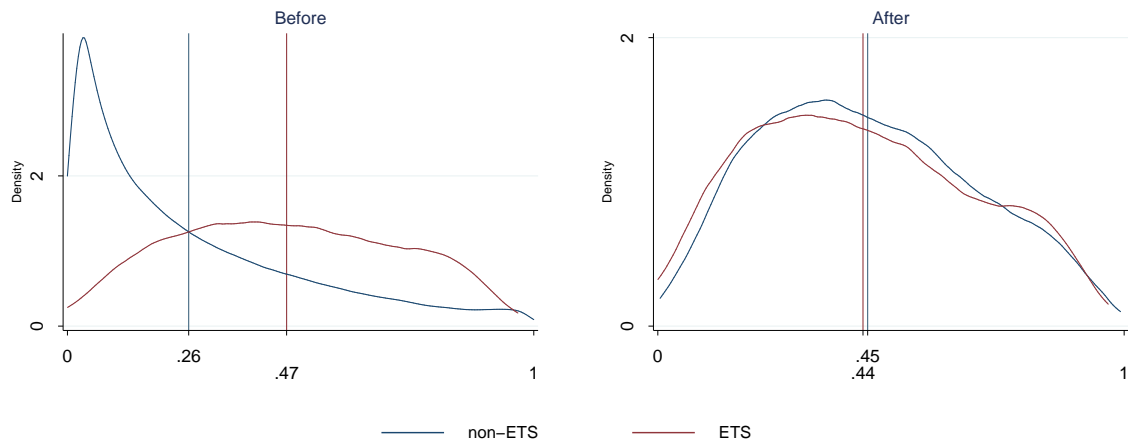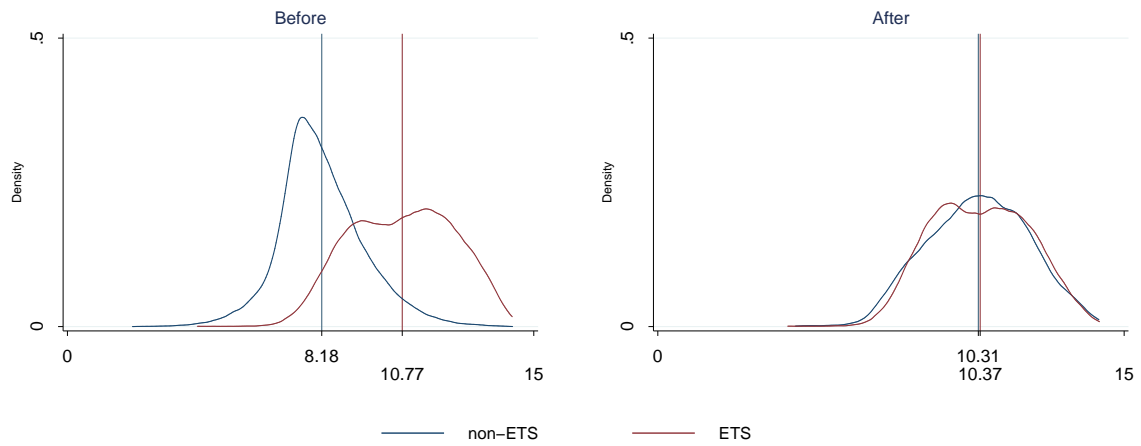**Figure 5:** Tangible fixed asset ratio in 2004 before and after balancing

Figure 6: Operating revenue (in logs) in 2004 before and after balancing
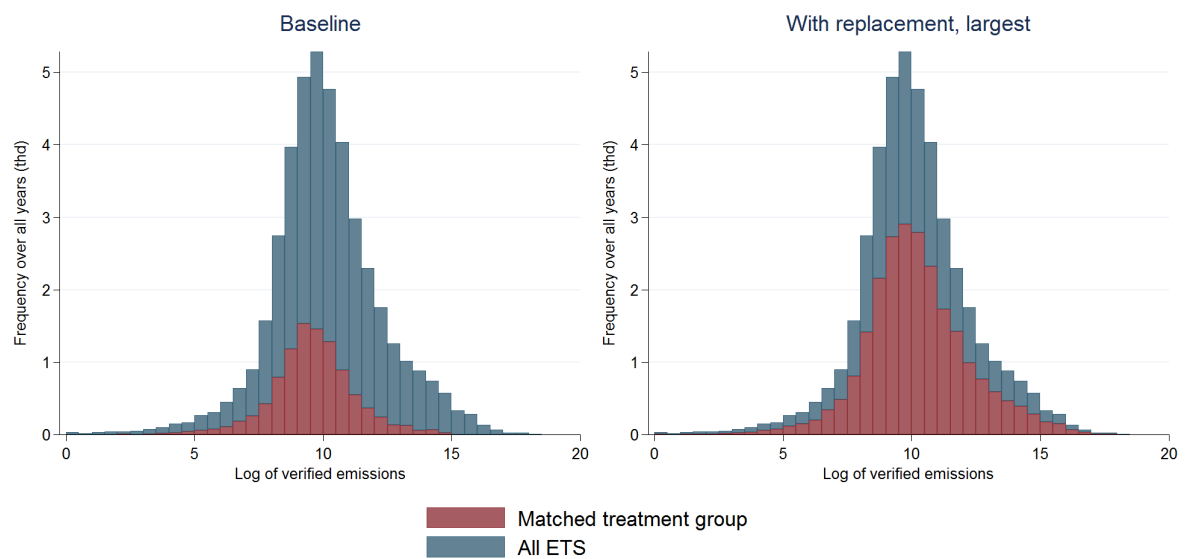
Figure 7: Matching the middle

A.3. Covariate balancing - Standardized differences

Table 10: Subsamples to assess effect heterogeneity

	(1) (Baseline)	(2) (Manufacturing)	(3) (Energy)	(4) (Carbon leakage list)
Very large firms excluded	✓	✓	✓	✓
Firms connected to the treatment group excluded	✓	✓	✓	✓
Firms with missing asset data excluded	✓	✓	✓	✓
Sector	All	Manuf.	Energy	CLL only
NACE code	2-digit	2-digit	2-digit	2-digit
Matching method	One-to-one	One-to-one	One-to-one	One-to-one
With replacement	No	No	No	No
Caliper	0.2	0.2	0.2	0.2
On support	325514	90289	1563	46659
Treatment group	1321	835	299	592
Control group	1321	835	299	592
Off support	594	377	221	399
Matched emissions (in percent)	4.4	5.4	1.7	1.3
Tangible fixed assets (in logs), 2004	1.0 | *in*	−0.1 | *in*	9.2 | *in*	−0.6 | *in*
Tangible fixed assets (in logs), 2003	1.0 | *in*	1.8 | *in*	11.5 | *in*	−0.9 | *in*
Tangible fixed assets (in logs), 2002	0.1 | *in*	2.2 | *in*	10.7 | *in*	−1.6 | *in*
Total assets (in logs), 2004	7.2 | *in*	4.5 | *in*	14.7 | *in*	9.4 | *in*
Total assets (in logs), 2003	7.3 | *in*	5.4 | *in*	17.4 | *in*	9.2 | *in*
Total assets (in logs), 2002	7.1 | *in*	6.6 | *in*	16.0 | *in*	10.1 | *in*
Tangible fixed asset ratio, 2004	−5.7 | *out*	−10.1 | *out*	−2.3 | *out*	−24.4 | *out*
Tangible fixed asset ratio, 2003	−5.1 | *out*	−5.5 | *out*	−2.4 | *out*	−22.0 | *out*
Tangible fixed asset ratio, 2002	−6.1 | *out*	−6.2 | *out*	2.0 | *out*	−25.8 | *out*
Operating revenue (in logs), 2004	4.0 | *in*	6.6 | *in*	12.2 | *in*	12.5 | *in*
Operating revenue (in logs), 2003	4.1 | *in*	6.7 | *in*	13.9 | *in*	11.2 | *in*
Operating revenue (in logs), 2002	3.8 | *in*	6.6 | *in*	13.4 | *in*	11.9 | *in*
Profit ratio, 2004, winsorized	5.4 | *in*	−11.7 | *in*	24.7 | *in*	−4.6 | *in*
Profit ratio, 2003, winsorized	−1.3 | *in*	−15.2 | *in*	21.1 | *in*	−14.8 | *in*
Profit ratio, 2002, winsorized	−2.1 | *in*	−14.1 | *in*	13.5 | *in*	−15.1 | *in*
Investment ratio, 2004	−2.9 | *in*	−12.7 | *in*	−24.2 | *in*	−6.8 | *in*
Investment ratio, 2003	3.0 | *in*	−7.7 | *in*	3.2 | *in*	−8.4 | *in*
Date of incorporation	−2.1 | *in*	0.9 | *in*	−9.6 | *in*	−3.4 | *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 implausible matches.

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

Table 11: Manufacturing samples

	(1) (Manufacturing)	(2) (NACE 3-digit)	(3) (Balanced MNE status)
Very large firms excluded	✓	✓	✓
Firms connected to the treatment group excluded	✓	✓	✓
Firms with missing asset data excluded	✓	✓	✓
Balancing on 2004 MNE status			✓
Sector	Manuf.	Manuf.	Manuf.
NACE code	2-digit	3-digit	2-digit
Caliper	0.2	0.05	0.2
On support	90289	89979	90241
Treatment group	835	525	787
Control group	835	525	787
Off support	377	687	425
TFAS, PPI adjusted, in logs	−0.1 │ in	0.6 │ in	6.4 │ in
TFAS, PPI adjusted, in logs, first lag	1.8 │ in	1.4 │ in	7.7 │ in
TFAS, PPI adjusted, in logs, second lag	2.2 │ in	1.2 │ in	7.9 │ in
TOAS, PPI adjusted, in logs	4.5 │ in	11.8 │ in	11.0 │ in
TOAS, PPI adjusted, in logs, first lag	5.4 │ in	12.8 │ in	11.9 │ in
TOAS, PPI adjusted, in logs, second lag	6.6 │ in	13.3 │ in	13.3 │ in
TFAS/TOAS	−10.1 │ out	−26.3 │ out	−7.6 │ out
TFAS/TOAS, first lag	−5.5 │ out	−24.7 │ out	−4.1 │ out
TFAS/TOAS, second lag	−6.2 │ out	−25.5 │ out	−5.5 │ out
OPRE, PPI adjusted, in logs	6.6 │ in	19.1 │ in	13.1 │ in
OPRE, PPI adjusted, in logs, first lag	6.7 │ in	19.6 │ in	12.6 │ in
OPRE, PPI adjusted, in logs, second lag	6.6 │ in	19.9 │ in	13.3 │ in
Profit ratio, 1OPPL OPRE lag, Winsorized fraction .01	−15.2 │ in	−15.2 │ in	−12.5 │ in
OPPL OPRE lag2, Winsorized fraction .01	−14.1 │ in	−15.6 │ in	−7.6 │ in
Delta Tangible Fixed Assets / Average Total Assets	−12.7 │ in	−10.8 │ in	−9.7 │ in
Delta Tangible Fixed Assets / Average Total Assets, first lag	−7.7 │ in	−12.0 │ in	−6.0 │ in
Date of incorporation	0.9 │ in	−14.1 │ in	−6.8 │ 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 12: Matching with replacement, all sector samples

	(1) (Baseline)	(2) (With large firms)	(3) (Without restrictions)	(4) (Simple balancing)
Very large firms excluded	✓			
Firms connected to the treatment group excluded	✓	✓		
Firms with missing asset data excluded	✓	✓		
Sector	All	All	All	All
NACE code	2-digit	2-digit	2-digit	2-digit
Matching method	One-to-one	One-to-one	One-to-one	One-to-one
With replacement	Yes	Yes	Yes	Yes
Caliper	0.2	0.2	0.2	0.2
On support	326026	328525	556390	818798
Treatment group	1833	2021	2804	3339
Control group	891	979	1647	1973
Off support	82	199	89	94
Matched emissions (in percent)	11.1	25.7	39.8	51.8
Tangible fixed assets (in logs), 2004	13.0 │ *in*	13.5 │ *in*	7.0 │ *in*	6.5 │ *in*
Tangible fixed assets (in logs), 2003	12.4 │ *in*	12.8 │ *in*	6.8 │ *in*	8.3 │ *out*
Tangible fixed assets (in logs), 2002	10.7 │ *in*	11.0 │ *in*	5.8 │ *in*	9.6 │ *out*
Total assets (in logs), 2004	17.3 │ *in*	17.1 │ *in*	10.1 │ *in*	10.3 │ *in*
Total assets (in logs), 2003	16.9 │ *in*	16.7 │ *in*	10.3 │ *in*	10.0 │ *out*
Total assets (in logs), 2002	16.6 │ *in*	16.0 │ *in*	10.1 │ *in*	11.0 │ *out*
Tangible fixed asset ratio, 2004	3.5 │ *out*	3.2 │ *out*	−1.9 │ *out*	−2.3 │ *out*
Tangible fixed asset ratio, 2003	3.7 │ *out*	3.2 │ *out*	−1.5 │ *out*	1.8 │ *out*
Tangible fixed asset ratio, 2002	0.0 │ *out*	−0.7 │ *out*	−3.3 │ *out*	3.0 │ *out*
Operating revenue (in logs), 2004	11.8 │ *in*	10.3 │ *in*	7.5 │ *in*	5.8 │ *in*
Operating revenue (in logs), 2003	11.9 │ *in*	10.3 │ *in*	7.9 │ *in*	7.0 │ *out*
Operating revenue (in logs), 2002	10.4 │ *in*	9.5 │ *in*	8.6 │ *in*	5.1 │ *out*
Profit ratio, 2004, winsorized	3.0 │ *in*	1.0 │ *in*	6.6 │ *in*	2.3 │ *in*
Profit ratio, 2003, winsorized	4.9 │ *in*	3.9 │ *in*	5.6 │ *in*	−1.5 │ *out*
Profit ratio, 2002, winsorized	−6.7 │ *in*	−6.0 │ *in*	4.5 │ *in*	0.6 │ *out*
Investment ratio, 2004	0.8 │ *in*	2.0 │ *in*	−2.7 │ *in*	−4.9 │ *out*
Investment ratio, 2003	10.1 │ *in*	12.3 │ *in*	3.5 │ *in*	−9.1 │ *out*
Date of incorporation	4.2 │ *in*	4.5 │ *in*	−4.9 │ *in*	−4.0 │ *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 implausible matches.

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 13: Matching with replacement, manufacturing samples

	(1) (Baseline)	(2) (With large firms)	(3) (Without restrictions)	(4) (Simple balancing)
Very large firms excluded	✓			
Firms connected to the treatment group excluded	✓	✓		
Firms with missing asset data excluded	✓	✓		
Sector	Manuf.	Manuf.	Manuf.	Manuf.
NACE code	2-digit	2-digit	2-digit	2-digit
Matching method	One-to-one	One-to-one	One-to-one	One-to-one
With replacement	Yes	Yes	Yes	Yes
Caliper	0.2	0.2	0.2	0.2
On support	90540	90834	143233	190635
Treatment group	1086	1150	1700	2000
Control group	604	603	1046	1220
Off support	126	246	120	130
Matched emissions (in percent)	11.5	17.5	31.8	39.4
Tangible fixed assets (in logs), 2004	7.7 | *in*	7.2 | *in*	5.3 | *in*	4.9 | *in*
Tangible fixed assets (in logs), 2003	8.8 | *in*	7.2 | *in*	5.3 | *in*	7.3 | *out*
Tangible fixed assets (in logs), 2002	9.1 | *in*	8.1 | *in*	5.9 | *in*	7.1 | *out*
Total assets (in logs), 2004	10.3 | *in*	10.5 | *in*	9.0 | *in*	9.1 | *in*
Total assets (in logs), 2003	10.9 | *in*	10.7 | *in*	9.4 | *in*	9.4 | *out*
Total assets (in logs), 2002	12.2 | *in*	11.5 | *in*	10.3 | *in*	9.7 | *out*
Tangible fixed asset ratio, 2004	−2.6 | *out*	−4.6 | *out*	−7.3 | *out*	−9.3 | *out*
Tangible fixed asset ratio, 2003	0.1 | *out*	−3.5 | *out*	−7.1 | *out*	−5.8 | *out*
Tangible fixed asset ratio, 2002	−1.6 | *out*	−3.4 | *out*	−8.3 | *out*	−7.5 | *out*
Operating revenue (in logs), 2004	11.6 | *in*	12.2 | *in*	12.0 | *in*	12.2 | *in*
Operating revenue (in logs), 2003	11.5 | *in*	11.9 | *in*	11.7 | *in*	11.1 | *out*
Operating revenue (in logs), 2002	11.5 | *in*	13.1 | *in*	12.4 | *in*	10.5 | *out*
Profit ratio, 2004, winsorized	−9.7 | *in*	−13.8 | *in*	−3.1 | *in*	3.6 | *in*
Profit ratio, 2003, winsorized	−15.2 | *in*	−18.7 | *in*	−4.0 | *in*	−6.4 | *out*
Profit ratio, 2002, winsorized	−14.6 | *in*	−21.0 | *in*	−3.8 | *in*	0.6 | *out*
Investment ratio, 2004	−7.2 | *in*	−2.8 | *in*	−2.4 | *in*	−13.6 | *out*
Investment ratio, 2003	−4.6 | *in*	−6.3 | *in*	−3.8 | *in*	−13.3 | *out*
Date of incorporation	10.2 | *in*	3.8 | *in*	−7.6 | *in*	−0.3 | *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 implausible matches.

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.4. Baseline Summary Statistics

Table 14: 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

A.5. Country shares in emissions, raw data vs. matched samples

Table 15: Country shares in emissions, raw vs. matched sample:
All sectors, matching w. replacement, simple balancing

Country	Sum	
	Raw	Treatment
AT	1.60%	0.22%
BE	2.58%	4.38%
BG	1.37%	2.04%
CY	0.20%	0.00%
CZ	4.03%	5.33%
DE	23.90%	21.21%
DK	1.33%	0.19%
EE	0.69%	1.16%
ES	8.01%	10.57%
FI	1.90%	0.67%
FR	5.98%	5.40%
GB	12.23%	12.28%
GR	3.40%	0.65%
HU	1.24%	1.94%
IE	0.97%	0.00%
IT	10.01%	15.13%
LT	0.31%	0.16%
LU	0.12%	0.00%
LV	0.14%	0.14%
NL	3.39%	1.33%
PL	10.39%	10.70%
PT	1.47%	2.27%
RO	2.11%	1.37%
SE	1.01%	1.15%
SI	0.44%	0.79%
SK	1.17%	0.92%
Total	100.00%	100.00%

Table 16: Country shares in emissions, raw vs. matched sample: Manufacturing, matching w. replacement, simple balancing

Country	Sum	
	Raw-manufacturing	Treatment
AT	3.23%	0.90%
BE	4.75%	8.71%
BG	0.75%	1.04%
CY	0.02%	0.00%
CZ	3.44%	3.05%
DE	18.95%	20.79%
DK	2.47%	0.14%
EE	0.19%	0.49%
ES	9.63%	12.72%
FI	2.42%	0.73%
FR	11.32%	13.39%
GB	6.97%	2.38%
GR	2.20%	1.19%
HU	1.03%	1.96%
IE	0.55%	0.00%
IT	10.47%	16.00%
LT	0.53%	0.02%
LU	0.21%	0.00%
LV	0.17%	0.28%
NL	4.23%	0.64%
PL	7.11%	8.28%
PT	1.87%	3.29%
RO	2.33%	1.20%
SE	2.14%	1.26%
SI	0.35%	0.42%
SK	2.66%	1.11%
Total	100.00%	100.00%

Table 17: Country shares in emissions, raw vs. matched sample:
Manufacturing, matching w. replacement, with large firms

Country	Sum	
	Raw-manufacturing	Treatment
AT	3.23%	0.00%
BE	4.75%	6.37%
BG	0.75%	0.64%
CY	0.02%	0.00%
CZ	3.44%	3.11%
DE	18.95%	22.14%
DK	2.47%	0.00%
EE	0.19%	0.90%
ES	9.63%	9.41%
FI	2.42%	0.13%
FR	11.32%	12.05%
GB	6.97%	6.10%
GR	2.20%	2.02%
HU	1.03%	1.62%
IE	0.55%	0.00%
IT	10.47%	20.65%
LT	0.53%	0.01%
LU	0.21%	0.00%
LV	0.17%	0.53%
NL	4.23%	0.15%
PL	7.11%	9.22%
PT	1.87%	1.83%
RO	2.33%	1.31%
SE	2.14%	0.94%
SI	0.35%	0.62%
SK	2.66%	0.26%
Total	100.00%	100.00%