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DIW Berlin
German Institute for Economic Research
Mohrenstr. 58
10117 Berlin

Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
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Mitigation versus Competitiveness? Industry Compensation in the European Union Emissions Trading System*

Till Köveker[†‡]   Robin Sogalla[†‡]

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Abstract

Carbon pricing policies are usually combined with compensation for exposed firms to prevent adverse competitiveness effects. In cap-and-trade systems, this carbon cost compensation mostly occurs through free allocation of emission permits. Using an administrative panel of German manufacturing firms, this paper investigates how free allocation in the European Union Emissions Trading System affects firms' competitiveness and their incentives to reduce emissions. Leveraging a reform of free allocation rules in a continuous difference-in-differences design, we find that that a reduction of freely allocated emission permits decreased firms' emission intensity. Our results suggest that this decrease is driven by energy efficiency improvements instead of outsourcing of emission intensive production. On the other hand, we do not find statistically significant effects on firms' employment, sales, value added, investments and exports – indicating that the reduction in free permits did not reduce firms' competitiveness.

JEL-Classification: Q54, Q58, H23, D22, F18

Keywords: Cap and Trade; Permit Allocation; Industry Compensation; Greenhouse Gas Emissions; Competitiveness; Manufacturing Firms

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[†]DIW Berlin

[‡]Technical University Berlin

1 Introduction

Carbon pricing is one of the most widespread policies to incentivize climate change mitigation. The majority of carbon pricing initiatives covering industry include some form of compensation or exemptions to preserve the competitiveness of the regulated industries (Venmans et al. 2020; Sato et al. 2022). With carbon taxes, competitiveness protection typically involves exempting some firms or sectors from paying the carbon tax whose international competitiveness is deemed to be at risk. In cap-and-trade systems, protection usually takes the form of allocating emission permits for free. These free allowances provide large implicit transfers to industry. For example, in the European Emission Trading System (EU ETS), they amounted to more than 400 bn. EUR[1][2] between 2005 and 2024. Yet, empirical evidence on their effectiveness in protecting firms' competitiveness remains scarce.

Free allowances are usually linked to historical emissions or to historical production volumes. In theory, they do not affect firms' marginal costs as using free allowances always carries an opportunity cost. They would thus only affect competitiveness via the extensive margin as firms lose their free allowances if they shut down or relocate plants. In practice, free allowances may however still affect marginal costs if firms anticipate that their current activity may serve as a base for future free allocation or if free allowances are dynamically linked to current production volumes.

Moreover, free allocation might undermine firms' incentives to reduce their emissions. While the Coase theorem (Coase 1960) implies that, under certain conditions,[3] the initial allocation of pollution rights theoretically should not undermine incentives to reduce emissions, the theorem is often not fully applicable to real-world cap-and-trade systems. In practice, free allocation rules and their specific features may distort such incentives in multiple ways. For example, firms may strategically alter the current production or emissions anticipating that this could increase their free allowances in the future (Neuhoff et al. 2006; Rosendahl 2008; Harstad and Eskeland 2010).

In this paper, we empirically investigate the ambiguous effects of free allowances on firms' competitiveness and incentives to reduce emissions. Using an administrative panel of German manufacturing firms linked to information on their regulated emissions and freely allocated allowances from the European Union Transaction Log (EUTL), we exploit a reform of free allocation rules in the EU ETS in 2013 to evaluate the causal effect of free allowances on various firm-level outcomes.

In the first two phases of the EU ETS from 2005 - 2012, the number of freely allocated allowances to an industrial installation[4] was determined by its historical emissions - so-called *grandparenting*. As member states had to allocate least 95% of permits for free in phase I and at least 90% for free in phase II, the large majority of emission permits were distributed

1. Own calculation.
2. This figure is almost as high as the annual federal budget of Germany – the EU's largest economy.
3. The most important ones are that pollution rights are clearly defined and that transaction costs are negligible.
4. The EU ETS is applied at the installation level. Thus, one firm can have several regulated installations.

free of charge until 2012(2003/87/EC 2003, Article 10).[5] With the start of the third phase in 2013, the rules for free allocation in manufacturing changed to so-called *benchmarking*.[6] With benchmarking the number of free allowances are calculated as the product of a sector-specific emission-intensity benchmark and an installation's historical production level. Because the benchmark value corresponds to the average of the first decile of the emission intensity distribution, most installations experienced a reduction of their freely allocated emission permits. However, the change in free allocation was heterogeneous across firms, as it depended on a firm's amount of overallocation in phase II and on the distance of its installations' emission-intensity to the sector-specific benchmark.

We use this heterogeneous change in free allocation to apply a continuous difference-in-differences design, where the treatment dose is a firm's reduction in free allowances. The main identification challenge is that firms with a higher treatment dose tend to have installations with a higher emission-intensity than low-dose firms, and, thus, may also differ in other characteristics. To improve the comparability of high-dose and low-dose firms we apply entropy balancing. This balancing re-weights the sample in order to remove the correlation of the treatment dose with the observable characteristics. Intuitively, it gives more weight to low-dose firms that resemble high dose firms and vice-versa.

We do not find any evidence that the reduction in free allowances negatively affected firm's competitiveness. Thus, on average, we estimate insignificant effects on sales, value added, exports, investments, capital and employment. On the other hand, we find that the reduction of free allowances due to the switch to benchmarking reduced firms' emission intensity. A heterogeneity analysis by sector reveals that this is predominately driven by emission savings in the chemical and glass industry. Our results point to an increase in the energy efficiency as the main mechanism behind this result, while we do not find any evidence for carbon leakage as both the effect on imports and emissions embodied in imported goods are not significantly affected by the change in free allowances.

The rest of the paper proceeds as follows: The related literature is reviewed in Section 2. We proceed by describing the institutional setting in Section 3 and the data in Section 4. In Section 5 we explain our empirical strategy and discuss identification. The empirical results of the analysis are presented and discussed in Section 6. Section 7 concludes.

2 Literature

We primarily contribute to the literature on the environmental and competitiveness effects of carbon tax exemptions and carbon cost compensations.

First, we contribute to studies that analyze the effect of carbon cost compensations on emissions in cap and trade systems. Theoretically, our analysis relates to the Coase Theorem (Coase 1960) and the independence property in cap-and-trade systems, according to which the

5. In practice, most firms were even overallocated, meaning that they obtained more free allowances than their annual emissions.

6. Benchmarking was already used in earlier years for the power sector. For the power sector, free allocation was then completely abolished in 2013, as there is no relevant risk of carbon leakage in the power sector.

initial permit allocation should not affect emissions (Montgomery 1972). Hahn and Stavins (2011) document that this independence property hinges on several assumption, such as the absence of transaction costs, competitive markets and no uncertainty about allowance prices.

Empirically, Fowlie and Perloff (2013) find that the independence property seems to hold in California's cap-and-trade program of NO_x and SO_x emissions. Moreover, the empirical evidence suggests that the independence property equally tends to hold for most electricity producers regulated under the EU ETS. Ellerman and Reguant (2008) do not find evidence that the share of free allocation matters for the emissions of Spanish coal power plants in the first phase of the EU ETS. Zaklan (2023) analyzes the impact of the switch from free allocation to auctioning on emissions of electricity plants. Exploiting exemptions for power producers in some European countries in a difference-in-differences design, he finds - in line with the independence property - that this switch did not affect emissions on average. However, his results suggest that small emitters reduced their emissions once facing a decrease in free allowances.

On the other hand, the existing empirical evidence points to a violation of the independence property for energy-intensive producers regulated under the EU ETS. Interviewing managers of plants in the ceramics, cement and lime sector, Venmans (2016) documents that they report higher incentives to invest into abatement technology when they receive less free allowances than needed to comply with the EU ETS. Dechezleprêtre et al. (2023) find that the emission reduction effect of the EU ETS is negatively correlated to the ratio of free allowances to emissions.

More closely related to our setting, some studies investigate the effects of free allocation exploiting the introduction of benchmarking in 2013. However, in contrast to our study, they rely on across-sector variation in free allowances.

Vivo and Marin (2018) find that plants in carbon-leakage-risk sectors, which experienced a lower reduction in free allocation in 2013, have a higher growth rate of emissions. Locatelli et al. (2022) confirm this finding for Italian manufactures. Also focusing on Italian industrial firms, Guerriero and Pacelli (2023) finds that plants in sectors with larger free allocation reductions reduced their emission intensity.

The above studies rely on binary treatment indicators to compare firms in sectors deemed to be at risk of carbon leakage with firms in sectors without carbon leakage risk. In the EU ETS sectors with high carbon intensity and/or trade exposure are defined as carbon leakage risk sectors, and sectors with low trade intensity and low carbon intensity as sectors without carbon leakage risk. As detailed in Section 3, the latter sectors experienced a much stronger relative reduction in free allowances after the introduction of benchmarking than the carbon leakage risk sectors. In these studies, which rely on across sector differences in free allocation reductions, the sectors without carbon leakage risk usually serve as the treatment group and the carbon leakage risk sectors as the control group.

This is problematic due to several reasons. The carbon leakage risk sectors tend to be much more energy-intensive and more upstream than the sectors with low carbon leakage risk. The control sectors are thus technologically very different and have different abatement options and a different abatement potential than the treated sectors. Moreover, the carbon leakage risk sectors are exposed to much more international competition and produce less differentiated products than the treated sectors with low carbon leakage risk. Thus, free allocation changes may have different effects on competitiveness-related variables – such as sales, exports, and imports – in carbon leakage risk sectors than in other sectors .It is therefore very questionable if the carbon leakage risk sectors can serve as a reliable control group for non-carbon leakage risk sectors. Moreover, the estimated treatment effect of these studies is for non-carbon leakage risk sectors, meaning sectors with low carbon and low trade intensity. Even if this effect was correctly estimated, it is unlikely that it has much external validity to understand the effects of a removal of free allowances in carbon leakage risk sectors with high carbon and trade intensity, which account for the large majority of regulated installations and for more than 95% of regulated emissions (see Figure1).

We contribute to this literature by applyingan identification strategy that does not hinge on across sector variation in free allowances and therefore does not use carbon leakage risk sectors as a counterfactual for non-carbon leakage risk sectors. Instead, we use continuous within-sector plant-level benchmarking-induced changes in free allocation as identifying variation. By combining this approach with entropy balancing we ensure that we compare firms that experienced a high post-benchmarking reduction of free allocation with firms from the same sector that saw little change in their free allowances and that are on average similar to the high-reduction firms.

Second, we contribute to the empirical literature on the effects of carbon pricing and carbon cost compensation on firms' competitiveness and on carbon leakage.[7]

A large part of this strand of literature has focused on evaluating the impact of the EU ETS.[8] Most studies find small or insignificant effects, concluding that the EU ETS did not adversely impact the competitiveness of exposed firms (Jaraitė and Di Maria 2016; Marin et al. 2018; Löschel et al. 2019; Dechezleprêtre et al. 2023; Colmer et al. 2024; Bremer and Sommer 2025). Moreover, several papers suggest that the EU ETS has not led to carbon leakage. Using a gravity design, Naegele and Zaklan (2019) do not estimate significant effects of the EU ETS on net imports and on net imports of embodied carbon. Studies using firm-level data confirm this finding. Dechezleprêtre et al. (2022) do not find evidence that multinational companies regulated under the EU ETS shifted their emissions to locations outside of the EU. Colmer et al. (2024) estimate an insignificant effect of the EU ETS on imports for French manufacturing firms suggesting that there was no significant outsourcing of carbon-intensive production. Finally, Koch and Basse Mama (2019) on average do not find evidence for investment leakage for EU ETS regulated firms, except for a small subsample of manufacturing firms that do not operate in energy-intensive and emission-intensive sectors.
However, apart from Bremer and Sommer (2025) the above studies focus on phase I and II of the EU ETS. Those including the third phase starting in 2013 provide suggestive evidence that the EU ETS increased the emissions embodied in imports (Wang and Kuusi 2024), leading to a switch of French manufacturing firms towards suppliers in non-regulated countries (Coster et al. 2024) and a displacement of emissions within multinationals (Känzig et al. 2024).

7. See Venmans et al. (2020) for an overview on the competitiveness impacts of carbon pricing.
8. See Verde (2020) for a focus on studies of the EU ETS and its impact on competitiveness and carbon leakage.

While there exist many studies investigating the impact of the EU ETS on measures of competitiveness and carbon leakage, causal ex-post evaluation on the effects of carbon cost compensation in the form of free allowances on competitiveness and carbon leakage remains scarce. To our knowledge, the only study performing an empirical ex-post evaluation of the impact of free allocations in the EU ETS on firms' competitiveness is Locatelli et al. (2022). Using data for Italian manufacturing firms, they mostly estimate insignificant effects on productivity, export value and import value, but one of their estimates suggests lower entry into exporting. As mentioned above, their estimation strategy relies on comparing firms in carbon intensive and or trade exposed carbon leakage risk sectors with firms operating in sectors with low carbon intensity and low trade exposure. We discussed above the issues with this identification strategy.

The literature on competitiveness and carbon leakage effects of the EU ETS has shown that there were no significant, or only small effects on competitiveness and carbon leakage in the first two phases of the EU ETS. More recent studies find suggestive evidence of some carbon leakage occurring towards the end of phase 3. An open question remains to what extent the limited presence of carbon leakage in the first three phases was due to free allocation[9] or the relatively low allowance prices during this period (see Figure A.1).

This paper contributes to answering this question by applying a rigorous identification strategy to estimate the effect of free allocation on several firm outcomes related to competitiveness and carbon leakage. We thereby contribute to the understanding to what extent free allowances mediated potential anti-competitive effects of the EU ETS. By exploiting variation in free allowances of firms within the same sector we avoid the pitfalls of identification strategies relying on across sector variation in free allocation.

We also relate to the literature studying other types compensations or exemptions from environmental regulations. Ferrara and Giua (2022) analyze indirect carbon cost compensation under the EU ETS and find that it is related to a decrease in firms' turnover, value of total assets and employment. As their empirical strategy relies on between sector and between country variation in compensation, results may however be driven by sector-specific or country-specific outcome trends. Also focusing on indirect cost compensation, Basaglia et al. (2025) estimate the impact of granting compensation for higher electricity prices on manufacturing firms in the UK. Their results suggest that compensated firms increased their electricity consumption and sales, leaving their energy intensity unchanged. Gerster and Lamp (2024) analyze the effects of exemptions from the German renewable energy levy granted for manufacturing plants with high electricity consumption. They find that these tax exemptions increased plants' electricity consumption without affecting economic outcomes such as sales or employment. We complement this literature by studying the environmental and competitiveness effect of cost compensations through free allocation of emission permits.

Finally, we contribute to the literature on the design and targeting of carbon cost compensation. Several studies have analyzed how to target compensation at sectors with the highest

9. Several scholars have attributed the absence of competitiveness effects in the first two phases of the EU ETS to the high share of free allocations (Joltreau and Sommerfeld 2019; Verde 2020; Venmans et al. 2020).

carbon leakage risk (Martin et al. 2014b; Sato et al. 2015) or at firms where compensation has the strongest effects on their marginal relocation probabilities (Martin et al. 2014a). We add to this literature on the targeting of carbon cost compensation, by estimating sector-specific effects of free allocation removal, thereby contributing to a better understanding in which sectors compensation is needed.

3 Free allocation in the third Phase (2013-2020) of the EU ETS

As discussed in the introduction, firms received most of the emission permits required to comply with the EU ETS for free in the first two phases. After the switch from *grandparenting* to *benchmarking* in 2013, the quantity of freely allocated emission permits does not depend on an installation's historical emissions anymore, but on product specific emission intensity benchmarks and firms' historic activity levels (2011/278/EU 2011).[10] Thus, the number of free allowances installation i producing product s in year t, FA_{ist}, are calculated according to the following formula (European Commission 2015):

$$FA_{ist} = BM_s * HAL_i * CSCF_t * CLEF_{st},$$

where BM_s is the product benchmark corresponding to the average emissions of the 10% least CO_2-intensive installations producing product s.[11] HAL_i is the historical activity level of installation i indicating its median historical yearly production between 2005 - 2008 or 2009 - 2010. $CSCF_t$ is the cross-sectoral correction factor, which is uniform across installations and ensures that the total amount of freely allocated emission permits does not exceed the aggregate cap multiplied with the share of baseline emissions in the manufacturing sector. $CLEF_{st}$ is the carbon leakage exposure factor. This factor is 100% for all installations operating in sectors on the carbon leakage list and declining from 80% in 2013 to 30% in 2020 for all other installations. Installations in carbon leakage risk sectors thus receive the full benchmarked allocation (i.e. $BM_s * HAL_i * CSCF_t$), whereas those that are not only receive a share of the benchmark allocation for free.

Whether a sector is deemed to be at risk of carbon leakage (and thus included into the carbon leakage list) is generally determined via two quantitative criteria: the carbon intensity and the trade intensity. The carbon intensity is defined as the share of EU ETS induced carbon costs over gross value added (GVA). The trade intensity is defined as the value of non-EU exports + non-EU imports over the total EU-market size of the sector (EU production + extra-EU imports). A sector is deemed to be at risk of carbon leakage if (1) the carbon intensity is above 30%; or if (2) the trade intensity is above 30%; or if (3) carbon intensity is higher than 5% and

10. In some cases, where product specific benchmark emission intensities could not be determined, the number of free allowances is calculated applying "fallback" benchmarks, i.e. more general heat- or fuel-benchmarks. If neither of these fallback benchmarks can be applied, then the number of free allowances are determined using a "process emissions approach", which is based on historical emissions (European Commission 2015).

11. If an installation produces more than one product, it is divided into several "sub-installations". The boundaries of each sub-installation are set such that only one benchmark applies (European Commission 2015).

trade intensity is higher than 10%. [12]

Figure 1 illustrates that the carbon leakage list covers the bulk of German manufacturing emissions (more than 95%) and installations (more than 85%) regulated by the ETS. As discussed in Section 2, an identification strategy for the impact of benchmarking, which exploits the differential reduction between sectors with an without carbon leakage risk status, necessarily estimates a narrowly defined local treatment effect for the non-carbon leakage group covering less than 15% of installations and less than 5% of emissions, abstracting from the major part of regulated installations and emissions (besides the general identification issues related to identification strategies relying on cross-sector variation in free allowances discussed in Section 2).

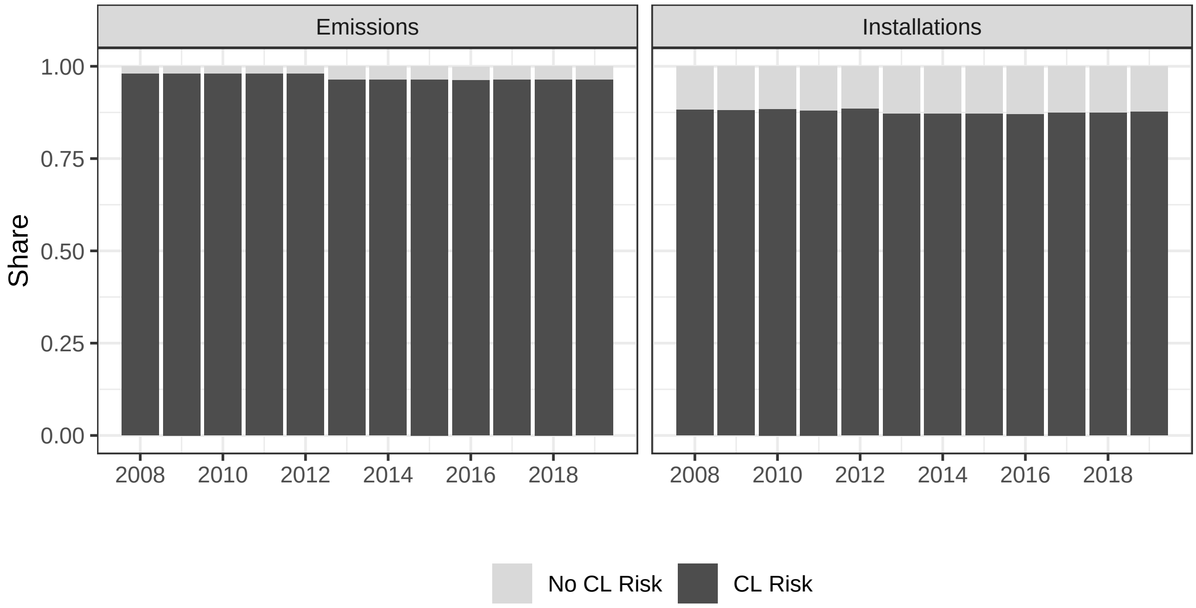

Figure 1: Share of emissions and installations on carbon leakage risk list

Note: The figure plots the share of emissions, and installations in German manufacturing separated by sectors, which fall under the carbon leakage risk list of 2014 (EC Decision C(2014) 7809)). The data source is the prepared data of the EU Transaction Log provided by Abrell (2024). This dataset indicates the NACE sector for most installations, which serves to identify manufacturing installations

Figure 2 shows that benchmarking lead to a reduction of free allowances. On average, installations in German manufacturing received more than 35% fewer emissions permits for free in 2013 compared to 2012.

12. Figure A.2 in the appendix provides a graphical illustration of the EU's carbon leakage risk criteria.

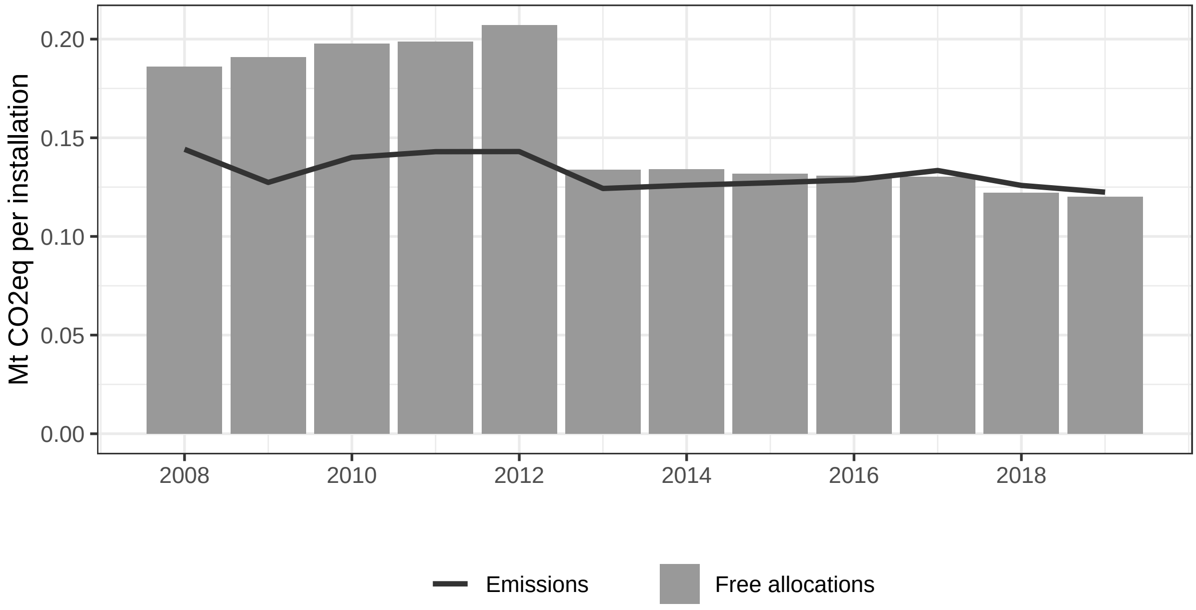

Figure 2: Free allocations and emissions per installation

Note: The figure plots the average number of free allocations and and emissions for ETS installations in the German manufacturing sector. The data source is the prepared data of the EU Transaction Log provided by Abrell (2024). This dataset indicates the NACE sector for most installations, which serves to identify manufacturing installations

4 Data

The main data source for this project is an administrative panel of German manufacturing firms ("Amtliche Firmendaten für Deutschland" (AFiD)).[13] This dataset consists of different modules.[14] We combine three modules of this dataset. First, the *AFiD-Panel Manufacturing Firms* provides information on sales and employment for all German manufacturing firms with at least 20 employees. Moreover, a representative subsample reports their detailed cost measures including material spending and investments. Based on these data we calculate value added and capital stocks.

Second, the *AFiD-Module Energy Usage*, collects data on the physical quantity used, sourced and sold of different 14 different energy carriers for all German manufacturing plants with more than 20 employees, which we aggregate at the firm-level. These two datasets have been previously used to analyze the impact of the EU ETS on German manufacturing firms (see e.g. Wagner and Petrick (2014) and Löschel et al. (2019)) and we refer the interested reader to these papers for a detailed description of the data.

Third, we obtain data on imports and exports of firms from the module *AFiD-Panel Foreign Trade Statistics*, which covers firm-level trade flows at the 8-digit product level differentiated by

13. The data are not publicly available, but can be analyzed in regional research data centers of the German Statistical System.

14. For detailed metadata of the data modules used in this paper see RDC (2022, 2023b, 2023a).

partner countries for the period 2011 to 2019.[15]

We augment these data with information on the firms and installations regulated by the EU ETS, the number of freely allocated allowances and emissions per installation and year from Abrell (2024), which is based on the European Union Transaction Log (EUTL) and covers all installations that are regulated under the EU ETS. We merge this EU ETS data on free allowances and emissions to the AFiD-panel at the firm level via the company registration number, location of the registry and firm address.

The beginning of the third trading phase of the EU ETS not only involved a change in free allocation rules from grandparenting to benchmarking. The EU ETS was also extended to additional industrial activities. Thus, large parts of the chemical industry, the production of gypsum and the processing of ferrous metals have been newly regulated by the EU ETS since 2013. Moreover, the definition of combustion activities was extended beyond energy-related activities and the third phase involved some changes in the administrative classification and definition of installations. Some installations operated by the same operator at the same location that had been previously monitored as separate installations have been grouped together and recorded as a single installation since the start of the third phase (Deutsche Emissionshandelsstelle (DEHST) 2014).

The extension of the sectoral scope of the EU ETS is likely correlated with firm-level changes of free allowances in 2013 - the first year of benchmarking. If an additional installation of a firm is regulated in 2013, this installation will receive free allowances. Thus, this firms might appear to have received a higher number of free allowances in 2013 compared to 2012 even if all of its installations faced a reduction due to the introduction of benchmarking. To separate the benchmarking-induced change in free allowances in 2013, from changes in firm-level free allowances due to newly regulated installations, we only include installations in our sample that were already active in the second phase of the EU ETS. Due to analogous considerations, we drop installations that closed in 2012 if they belong to firms with no other installation.[16] For firms with several installations out of which at least one installations closed at the end of 2012, we need to understand if this installation actually closed or only appears to have closed because it was merged with another installation. In all these cases we manually check whether this installation is merged with another continuing installation and delete installations that actually closed at the end of 2012, whereas we keep those that have been merged to other installations in 2013.[17]

Moreover, we use the environmentally-extended input-output database Exiobase to calculate emissions embodied in imported products at the firm level.[18] Finally, we create an indicator whether a firm is in a carbon leakage risk sector based on the published carbon leakage risk

15. See Fauth et al. (2023) for a detailed description of the trade dataset.

16. This firm would appear to have a drop of free allocation to zero although it stopped being regulated by the EU ETS.

17. We need to keep installations that were merged to other installations at the beginning of phase 3 as deleting them (in phase 2) may lead to spurious correlation between 2013-changes in free allowances and changes in emissions at the firm-level.

18. See Stadler et al. (2018) for a description of Exiobase and Köveker et al. (2025) for details on the calculation of emissions embodied in firm-level imports for German manufacturing firms.

sectors at a four digit sector level.

Our sample covers the years 2008 to 2019 and hence the entire second and third trading period except for the year 2020, which we omit due to the COVID-19 pandemic. We clean the dataset by excluding observations with evident data entry errors[19] and delete outliers.[20] Moreover, we exclude firms that switch their main operating sector at a 2 digit level to ensure that our sector level results are not driven by changes in the composition of firms. Table 1 reports summary statistics of our final sample.

	Median	Mean	Std. dev.	N
Treatment (free allocation reduction in %)	30.05	30.18	27.38	3007
Value added (1,000,000 EUR)	50.51	551.49	2260.93	3007
Sales (1,000,000 EUR)	204.95	1927.08	7542.46	3007
Employees (number)	565	3038.50	10601.33	3007
Investments (1,000,000 EUR)	7.26	61.67	249.98	3007
Capital stock (1,000,000 EUR)	161.74	867.31	2767.52	3007
Labor productivity (1000 EUR/employee)	96.29	203.45	865.99	3007
Imports (1,000,000 EUR)	22.43	493.23	2054.84	2312
Exports (1,000,000 EUR)	42.05	834.45	3904.71	2312
Emissions (1,000,000 tCO2eq)	0.04	0.41	1.47	3007
Emission intensity (tCO2eq/1000 EUR of value added)	1.21	4.32	11.13	3007
Emission intensity (tCO2eq/1000 EUR of sales)	0.31	1.16	2.34	3007
Emissions embodied in imports (1,000,000 tCO2eq)	0.02	0.27	1.52	2312
Energy intensity (kWh/EUR of value added)	8.71	15.49	25.67	3007
Energy intensity (kWh/EUR of sales)	2.21	3.76	5.59	3007
Share fossil fuels (%)	83.00	75.21	24.04	3007
Share electricity & district heat (1,000,000 EUR)	14.43	22.30	22.86	3007

Table 1: Descriptive statistics of key variables

5 Empirical strategy

The introduction of benchmarking in 2013 led to a stark overall reduction in the number of free allowances. We are interested in estimating the effect of this change in free allocations on various firm-level outcomes. Our empirical strategy relies on a continuous (or dosing) difference-in-difference design, in which we exploit the heterogeneous change in free allocation of emission permits that firms experienced following the switch from grandfathering to benchmarking. We define a continuous treatment variable, where the treatment dose corresponds to a firm's percentage reduction in freely allocated emission permits between 2012 and 2013:

$$d_i = \frac{FA_{i,2012} - FA_{i,2013}}{FA_{i,2012}}. \tag{1}$$

19. We exclude observations with negative free allowances, negative emissions, no more than one Euro of sales or no more than one worker. We also exclude firms that ever reported negative value added.

20. We drop firms whose percentage changes in free allowances were below the 1^{st} or above the 99^{th} percentile in 2013 - the year of our treatment. Similarly, we exclude firms whose percentage changes in emissions were below the 1^{st} or above the 99^{th} percentile in 2013 or if emissions increased by more than 100% in that year. Finally, we also compute the Cook's distance (Cook 1977) of each firm in our main specification for each of our main dependent variables and exclude the firm if its Cook's distance is above the 99^{th} percentile.

The treatment dose d_i is high for firms that experienced a large reduction in free allowances in 2013 and low for firms that experienced little change in their free allocation endowment after the introduction of benchmarking. The post-benchmarking change of free allocation varies across firms depending on the distance of their ETS installations to their product-specific benchmark value. As the benchmark value corresponds to the average of the first decile of the emission intensity distribution, the very large majority of firms have a positive treatment dose as most installations experienced a reduction in freely allocated emission permits. Firms with more emission intensive installations (compared to their respective sectoral benchmark) experienced a larger reduction of free allowances, and, thus, have a higher treatment dose. Firms with installations whose emission intensity is close to their sector-specific benchmark experienced little change in their freely allocated permits and accordingly have a low treatment dose.[21]

We use the following main specification to estimate the effect of changes in free allowances following the transition to benchmarking-based allocation:

$$ln(y_{it}) = \alpha_i + \eta_t + \beta\, d_i\, \mathbb{1}_{t \geq 2013} + \Psi_{it} + \varepsilon_{it}, \tag{2}$$

where y_{it} is the outcome of interest of firm i at time t, α_i and η_t are time and firm-fixed effects and Ψ_{it} includes baseline controls and sector dummies, both interacted with time fixed effects. The coefficient of interest is β, which indicates the percentage increase in the outcome y_{it} attributable to a a one-percent post-benchmarking reduction in free allowances. To account for the presence of zeros, we estimate (2) with the Pseudo-Poisson-Maximum-Likelihood estimator (PPML) proposed by Silva and Tenreyro (2006) for investments, exports, imports and emissions embodied in imports as dependent variables.

To identify the causal effect of d_i on the firm-level outcomes y_{it}, we rely on a set of well-known difference-in-differences assumptions.

The key identification assumption of this continuous difference-in-differences design is that of parallel trends of untreated potential outcomes between firms experiencing different doses d_i. The parallel trends assumption, thus, implies that firms' outcomes would on average have followed parallel paths, had their free allocations remained at the 2012 level, i.e. $d_i = 0$, regardless of their actual change in free allocations between 2012 and 2013. Put differently, the assumption requires that if the benchmarking reform would not have been introduced, outcomes would have evolved the same for firms that experienced small and large post-benchmarking changes in free allocations.

Testing parallel trends is infeasible given its counterfactual nature. We gauge the plausibility of parallel trends using an event study design, in which we replace the interaction of the treatment

21. Some firms have installations with a lower emission intensity than the sectoral benchmark. These firms even experienced an increase in their free allocation, and will have a negative treatment dose. However, this is only the case for a very low share of firms (8%) as the benchmark is the average of the first decile of a sector's emission intensity distribution. Moreover, the median dose of firms that experienced an increase in their free allowances, is in absolute value much smaller than the median dose of firms that experienced a reduction (10% vs. 32%).

variable and the post dummy with interactions of the treatment variable and year dummies:

$$ln(y_{it}) = \alpha_i + \eta_t + \sum_{\tau=2008,\neq 2012}^{2019} \beta_\tau \, d_i \, \mathbb{1}_{\tau=t} + \Psi_{it} + \varepsilon_{it}. \tag{3}$$

We omit the interaction of d_i with 2012 so that all event-study coefficients are measured relative to the last year before the introduction of benchmarking. If there were no differential outcome trends in the pre-period between firms with higher and lower doses d_i, then the event-study coefficients of the pre-period should not be significantly different from zero. Figure 3 and Figure A.4 support the assumption of parallel trends for all of our estimations.[22] However, parallel trends in the pre-period are only indicative of the required, but untestable, parallel trends in the post-period.

To improve the plausibility of the parallel trends assumption, we therefore additionally perform entropy balancing along a set of baseline covariates following Tübbicke (2022). This approach assigns weights to each observation such that the correlation between the treatment and the specified balancing covariates is minimized. Thus, it improves the comparability of high and low-dose firms. We use the logarithmic value of value added, labor, emissions and of the capital to labor and energy to labor ratio, as well as the share of electricity from the grid in total energy consumption as balancing variables. To gauge whether the entropy balancing is also successful in removing differences in unobserved confounders, we perform placebo tests by checking the correlation of the treatment-dose with covariates excluded from the balancing algorithm in the reweighted sample. Figure A.3 in the appendix shows that already before balancing, most balancing variables as well as placebo variables are uncorrelated with the treatment. The entropy balancing removes significant correlations of covariates with the treatment except for the capital labor ratio.[23]

Second, to interpret β in equation (2) as the causal effect of d_i on y_{it}, we additionally need to invoke the no treatment anticipation assumption. The German National Implementation Measures (NIM), which determined the number of free allocation each installation would receive after the introduction of benchmarking was published in May 2012. The information about firms' individual treatment doses was, thus, published just over half a year before the treatment onset leaving firms little time to adjust their operations in anticipation of the treatment.

Third, the treatment needs to be independent of any other changes that occurred in 2013, and which were both correlated with treatment assignment and the outcome. In 2013, there was a change in the eligibility criteria of the national Special Equalisation Scheme (Besondere

22. Only for investments, one of the pre-treatment event study coefficients is significantly different from zero at the 5%-level in 2008 – however, this may be related to the turmoil during financial crisis and is unlikely to indicate fundamental differences in pre-trends.

23. The entropy balancing algorithm sets the correlation of the balancing variables and the treatment variable exaclty to zero (Hainmueller 2012; Tübbicke 2022). We perform the entropy balancing on the cross-section of firms in our baseline year 2012. In Figure A.3 the correlation of balancing variables and the treatment variable is however not exactly zero due to several reasons: First, we truncate large weights to a maximum value of 2% – as suggested by Tübbicke (2022) – to limit on overly large influence by individual firms. Second, we drop firms with a Cook's distance above the 99^{th} percentile (as described in Section4. Finally, we apply the balancing weights to observations from all years of our unbalanced panel.

Ausgleichsregelung), which allows electricity-intensive firms to apply for a reduction of the Renewabl Energies Act levy (EEG-Umlage). To control for this regulatory change, we include a dummy indicating if a firm was affected by the change in eligibility criteria and interact it with year fixed effects. Moreover, with the beginning of the third trading period, EU ETS regulations on monitoring and free allocation of industrial waste gases were changed for some sectors (Ecofys 2009). To control for such changes, we include a firm's baseline waste gas production in 2012 interacted with year fixed effects. Finally, starting in 2013, the EU allowed countries to provide electricity price compensation to their national industries deemed to be at risk of carbon leakage, to compensate them for carbon costs in electricity prices. We control for the introduction of the electricity price compensation in Germany by including a firm's share of electricity that is eligible for compensation in the entropy balancing. We thereby ensure that the treatment dose d_i is not correlated to the amount of electricity price compensation that a firm receives.

Finally, we need to make one additional assumption as our setup is a continuous (or dosing) difference-in-differences design. For identification, we exploit the difference in outcome changes between high and low-dose firms. In this setup, we need to invoke the assumption that the average dose-response function is uncorrelated to treatment assignment. In other words, firms with a high dose would need to have had similar treatment effects, had they received a low dose, as low-dose firms that actually received a low dose (Callaway et al. 2024). The assumption that there is no correlation of the dose-response function with the actual treatment dose is more plausible if there is no correlation between the dose and observable covariates. Following Cook et al. (2023), we perform a balancing test, where we regress the treatment dose on various covariates. The results are summarized in Figure A.3 showing that there is no significant correlation between the treatment dose and observable covariates in the weighted sample that we use in our main estimation. As the entropy balancing also removed correlations of the treatment dose with covariates not included in the balancing algorithm, we can be confident that it was also successful in removing any potential correlation of the dose with the unobservable dose-response function.

6 Results

6.1 Effects on emission intensity

Table 2 shows the results of estimating (2) with outcomes related to firm's emission intensity. The first column indicates that the removal of free allocation due to the switch to benchmarking, lead to a significant decline in firms' emission intensity. Thus, a 10% reduction in free allocation induced firms to reduce their emissions per value added by around 2%. As the switch to benchmarking implied an average loss of free allowances equal to 30% (Table 1), the reform improved the emission intensity by 6% on average. Extrapolating our estimates to a full phase-out of free allocation implies an average emission intensity reduction of 20%. Thus, our results suggests that the transition to benchmarking and the associated free allocation removal have lead to modest emission intensity reductions, but did not induce deep decarbonization.[24]

An important question concerns the mechanisms behind this observed effect on emission intensity. Did firms reduce their emission intensity in production or did they outsource the most emission intensive production steps? The latter would signal carbon leakage as the emission intensity improvements are offset by an increase in emission intensive production elsewhere. Columns 2 - 4 show the estimated treatment effects on energy intensity and fuel switching. We do not find that the removal of free allowances had a significant effect on energy efficiency or that firms switched from fossil fuels towards electricity. Columns 5 and 6 provide evidence against carbon leakage driving the emission intensity improvements. The removal of free allocation does not seem to have induced firms to import emission intensive products, as the coefficient for firm-level imports and the emissions embodied are not significantly different from zero at any conventional threshold.

	Log Emission intensity	Log Energy intensity	Fossil fuel share	Electr. & distr. heat. share	Imports	Emissions emb. in imports
Treatment	-0.196**	-0.0316	0.00631	-0.0213	-0.0325	-0.138
	(0.0900)	(0.123)	(0.0256)	(0.0271)	(0.179)	(0.189)
Observations	3007	3007	3007	3007	2312	2312

Table 2: Emission effects

Notes: Regressions of the dependent variables in columns on the change in free allowances between 2013 and 2012 (Treatment) according to specification (2). Standard errors (in parenthesis) are clustered at the firm-level. Emission intensity and energy intensity are measured as emissions and energetic use of energy carriers relative to value added. Fossil fuel share is the share of oil, natural and industrial gases, coal and waste in the total energetic use of energy carriers. The third column shows the results for the share of electricity and district heating consumption in the total energetic use of energy carriers. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk list, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for electricity price compensation industry, and firms' baseline production of industrial gases. The first four columns are estimated using linear OLS and the last two with the Pseudo-Poisson-Maximum-Likelihood estimator.

The key assumption to interpret these results as causal is the one of parallel trends. Figure 3 shows the event-study estimate according to specification (3) for the dependent variables in Table 2. The 95% confidence intervals of all pre-treatment coefficients include the zero, which indicates that firms with high and low treatment doses did not have differential outcome trends prior to the reform. This supports the assumption that trends in untreated potential outcomes are also parallel after the reform.

24. In some cases, free allocation rules even create such adverse incentives that effective carbon prices for deep decarbonization become negative. For example, if a steel company that is regulated under the EU ETS and produces via the conventional BF-BOF (Blast Furnace - Basic Oxygen Furnace) route switched to the low-carbon H2-DRI-EAF route, then the company would have (until recently) lost it's entitlement to free allocations.

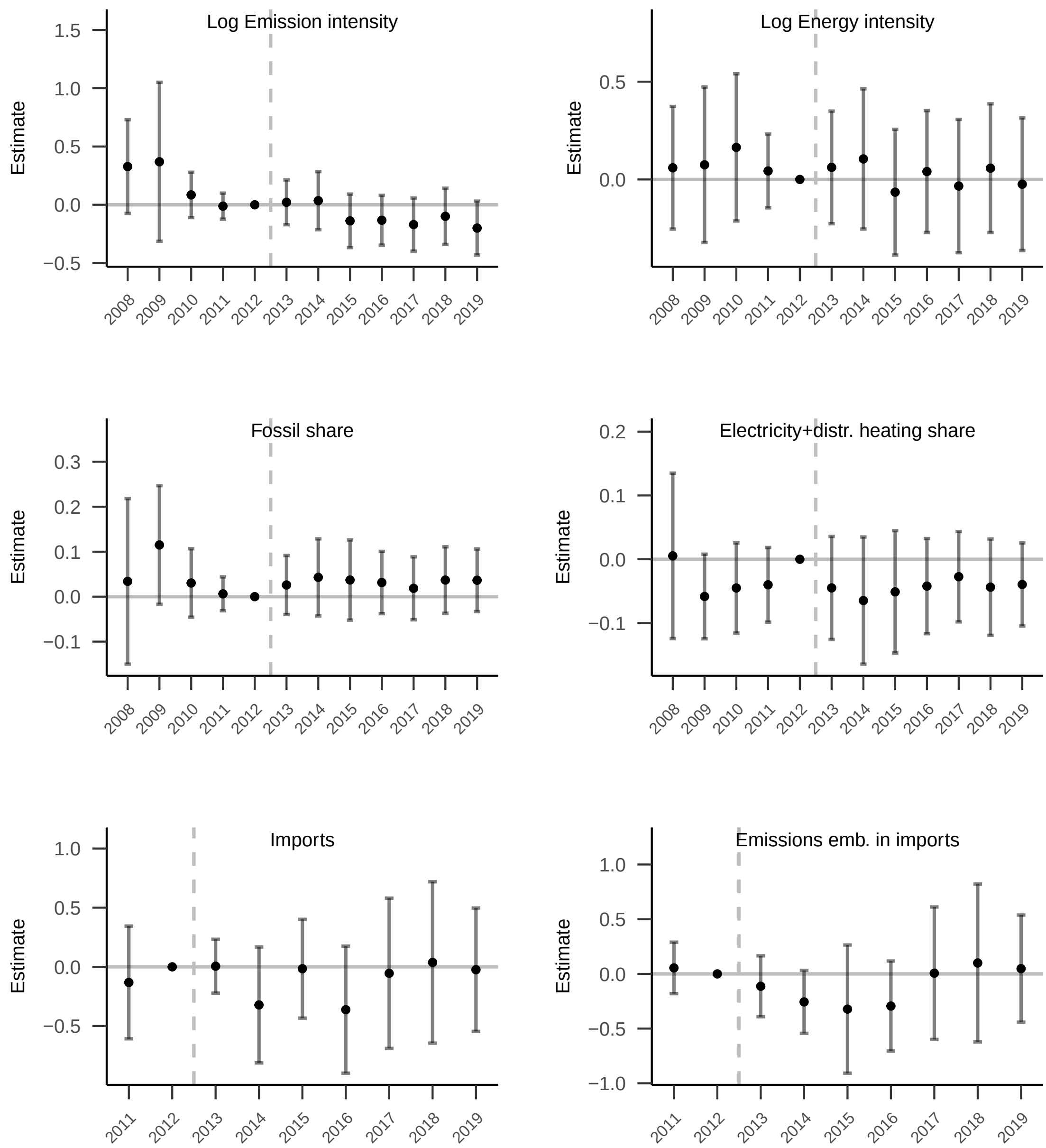

Figure 3: Event study estimates on outcomes related to firms' emission decisions

Notes: The point indicates the event study estimate according to specification (3) and the whiskers the corresponding 95% confidence interval based on standard errors clustered at the firm level. Emission intensity and energy intensity are measured as emissions and energetic use of energy carriers relative to value added. Fossil fuel share is the share of oil, natural and industrial gases, coal and waste in the total energetic use of energy carriers. The fouth panel column shows the event study for the share of electricity and district heating consumption in the total energetic use of energy carriers. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk list, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for electricity price compensation industry, and firms' baseline production of industrial gases. The first four columns are estimated using linear OLS and the last two with the Pseudo-Poisson-Maximum-Likelihood estimator.

Table A.1 shows that the negative emission intensity effect is robust to using emissions relative to sales instead of value added as the dependent variable. Moreover, our main estimation includes aggregate sector-specific[25] time trends; including sector-specifictime trends corresponding to the 2 digit NACE classification yields similar results (Tables A.2).

Next, we investigate the differential effects on the emission intensity by sector.[26] The left panel of Figure 5 shows that the removal of free allowances lead to significant emission intensity reductions in the chemicals, rubber and plastics sector and in the glass industry (in all other sectors, the coefficients are not significantly different from zero at the 5% level). Interestingly, the right panel of Figure 5 displays a similar pattern for the treatment effects on energy intensity: The removal of free allowances lead to significant energy intensity reductions in the same sectors, bolstering the hypothesis that the observed emission-intensity reductions have been driven by energy efficiency improvements (and not by deep decarbonization).
Our treatment effect estimates for the other variables related to fuel-switching and carbon leakage do not indicate that these mechanisms would explain the decline in firms' emission intensity (see Figure A.5). The reform-related reduction in free allowances did neither induce a significant decline in the share of fossil fuels nor a significant increase in the share of electricity and district heating in total energy consumption in any sectors. Moreover, we do not find evidence for an increase in firm-level imports and in emissions embodied in those imports for most sectors.[27]

All in all, the sector-level results suggest that the removal of free allocation lead to a reduction in the emission intensity via improvements in the energy efficiency, and that the effects are most pronounced for firms producing glass and chemicals, rubber or plastics.

25. In our main specification, we use aggregate sector dummies that correspond to the sector-definition that we use for the heterogeneity analysis. These aggregate sectors are based on NACE 2 and NACE 3 codes, and are more granular than the NACE 2 classification for energy-intensive and trade-exposed basic material sectors, e.g. in the case of glass, ceramics and cement. For other less energy-intensive manufacturing sectors, our sector definition is less granular than the NACE 2 classification.

26. The sectors are based on NACE 2 and NACE 3 codes, and are more granular than the NACE 2 classification for energy-intensive and trade-exposed basic material sectors, e.g. in the case of glass, ceramics and cement. For other less energy-intensive manufacturing sectors, our sector definition is less granular than the NACE 2 classification. This sector definition reflects the fact that most regulated EU ETS installations are in energy-intensive sectors, and only few regulated installations are in less energy-intensive manufacturing sectors allowing us to have a higher granularity in energy-intensive sectors than in less energy-intensive sectors, where we need to combine several NACE 2 codes to have a sufficient sample size for our estimation.

27. The only exception is refineries – in which case the observed increase in imports (and associated embodied emissions) rather seem to reflect an increase of intermediary trading activity of the firms with high treatment dosages as the sector's coefficients for exports and sales are also significantly positive (but not for value added).

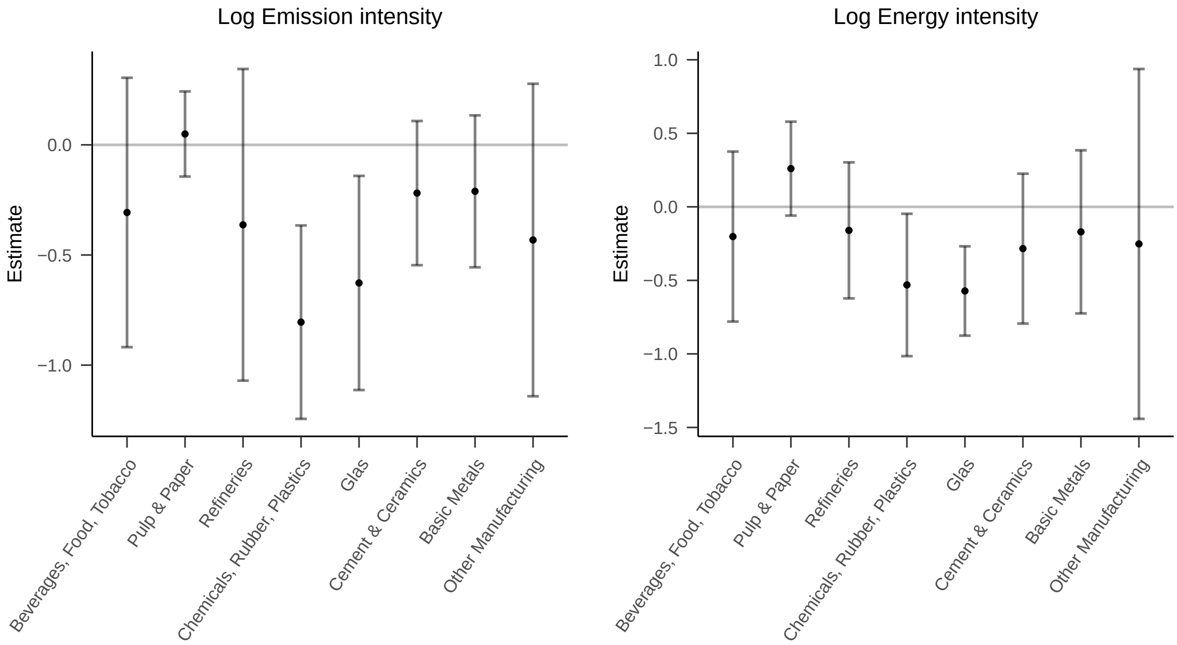

Figure 4: Effects on the emission and energy intensity by sector

Notes: The point indicates the estimate for the corresponding sector (3) and the whiskers the corresponding 95% confidence interval based on standard errors clustered at the firm level. Estimates based on a regression with an interaction of sector dummies and the treatment. Emission and energy intensity measured in terms of value added. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: Aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for eligible for electricity price compensation industry, and the baseline production of industrial gases.

6.2 Effects on competitiveness

This section examines whether the removal of free allocation negatively affected firms' competitiveness. Table 3 shows that the treatment did not have significant negative impacts on value added, employment, sales, capital, investments or exports. For none of the dependent variables and in none of the specifications we find a significant treatment effect. As shown in Figure A.4, parallel trends hold prior to the introduction of benchmarking for all of these dependent variables.[28] The treatment coefficients for all competitiveness related variables remain insignificant when using NACE 2 sectors instead of our own aggregate sector classification for the sector-speficic time trends (Table A.3).

The absence of competitiveness effects on average is in line with the previous literature on carbon pricing as discussed in Section 2. For most of the treatment period carbon prices were very low, only starting to rise above 10 EUR per ton in 2018 (see Figure A.1). However, the

28. As mentioned before, the only significant coefficient is the one on investments in 2008, which likely rather reflects the turmoil during the financial crisis rather than fundamentally different in pre-trends.

average effect might mask substantial heterogeneity across sectors, as the competitiveness effects potentially differ depending on the carbon intensity and exposure to international competition of firms.

	Log Value added	Log Employment	Log Sales	Log Capital	Investment	Exports
Treatment	0.0569	0.0484	0.0542	0.0143	0.0237	0.178
	(0.0766)	(0.0298)	(0.0444)	(0.0184)	(0.136)	(0.221)
Observations	3,007	3007	3007	3007	3007	2312

Table 3: Competitiveness effects

Notes: Regressions of the dependent variables in columns on the change in free allowances between 2013 and 2012 (Treatment) according to specification (2). Standard errors (in parenthesis) are clustered at the firm-level. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: 2-digit NACE sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk list, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for electricity price compensation industry, and firms' baseline production of industrial gases. The first four columns are estimated using linear OLS and the last two with the Pseudo-Poisson-Maximum-Likelihood estimator.

Figure 5 explores the heterogeneity of competitiveness effects across sectors. In none of the sectors, the removal of free allocation lead to a decline in value added, employment, sales or exports. If anything they are associated with an increase in sales of refineries and in other manufacturing. However, as discussed above, the increase in sales and exports of refineries with high treatment doses rather seems to indicate an increase of intermediate trading activity of these firms than changes in competitiveness. The positive effect on sales in other manufacturing should also be interpreted with caution as it may be due to the higher level of sectoral aggregation that we must accept in less emission-intensive manufacturing sectors with a low number of firms regulated under the EU ETS. The absence of adverse effects along the intensive margin on these measures of competitiveness is in line with the theoretical prediction discussed in the introduction that free allocation should not affect firms' marginal costs.

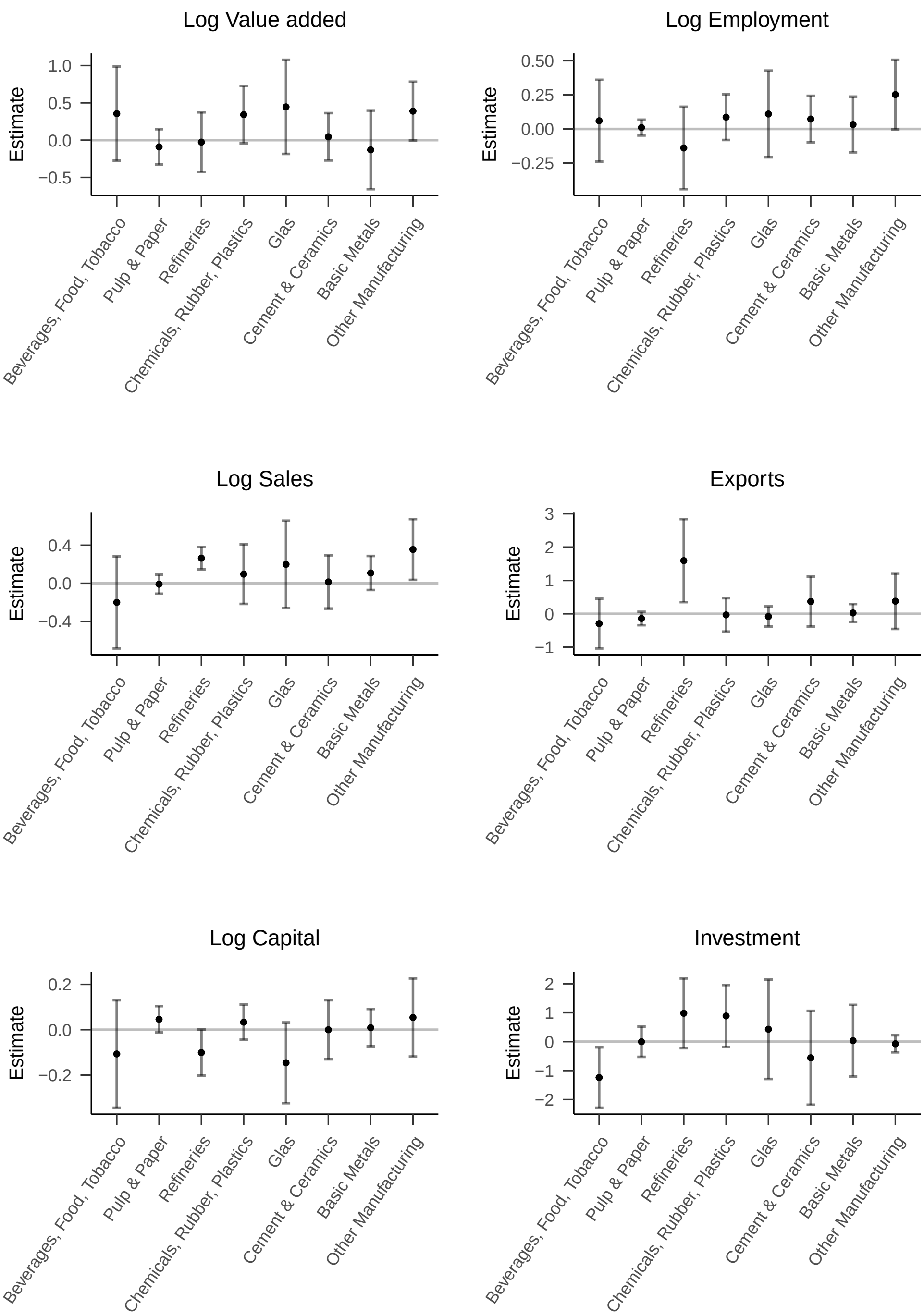

Figure 5: Competitiveness effects by sector

Notes: The point indicates the estimate for the corresponding sector (3) and the whiskers the corresponding 95% confidence interval based on standard errors clustered at the firm level. Estimates based on a regression with an interaction of sector dummies and the treatment. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: Aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for eligible for electricity price compensation industry, and the baseline production of industrial gases. Outcomes in logs estimated with linear OLS and investments and exports with the Pseudo-Poisson-Maximum-Likelihood estimator.

In contrast to the the absence of competitiveness effects for these operational decision variables, one may expect effects on strategic decision variables such as investments. A reduction of free allowances worsens firms' financial position and, thus, potentially their ability to make investments. Lower investments may later on also be reflected in lower capital stocks. However, Figure 5 shows that we only observe a significantly negative treatment effect on investment in the beverages, food and tobacco sector and no negative effects on capital. The free allocation removal thus did not seem to have had large effects on firms' investments and capital stocks by making firms more financially constrained.

7 Conclusion

Most cap-and-trade systems use free allowances for competitiveness protection. Since 2005 and during the first 20 years of the EU ETS – the world's largest emission trading system in terms of value (ICAP 2024) – emission permits worth several hundred billion EUR have been allocated free of charge to polluters. Given the economic magnitude of carbon cost compensation in the form of free allowances, there is surprisingly little empirical evidence on its effects.

In this paper, we exploit a change in free allocation rules of the EU ETS to empirically evaluate the effects carbon cost compensation in the form of free allowances on German manufacturing firms.

We find that a reform-induced reduction in free allowances incentivized firms to reduce their emission intensity – particularly in the glass and chemicals sectors. This reduction in emission intensity does not seem to be driven by investments into deep decarbonization but rather by improvements of firms' energy efficiency, as we find significant reductions of energy intensity in the same two sectors. This result casts doubts on whether the independence property of permit allocation holds in the manufacturing sector.

Moreover, our estimates imply that the reduction in free allowances did not harm firm's competitiveness, as we do not find significant effects on sales, value-added, exports, capital and investments on average.

Some caveats apply. First, our analysis covers the years 2008-2019 with low to moderate carbon prices in the EU ETS. It is possible that higher carbon prices would lead to different outcomes. Second, we only evaluate competitiveness effects along the intensive margin. Whether free allocation impacts firm closures and the set up of new plants in the EU or third countries is an interesting question for further research. Finally, our results are likely context-dependent with Germany being a developed economy embedded into the larger EU common market, such that many of its important trade partners are exposed to the same carbon price. Results may look different for other countries with different industry characteristics and a different trade structure.

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A Appendix

A.1 Additional graphs

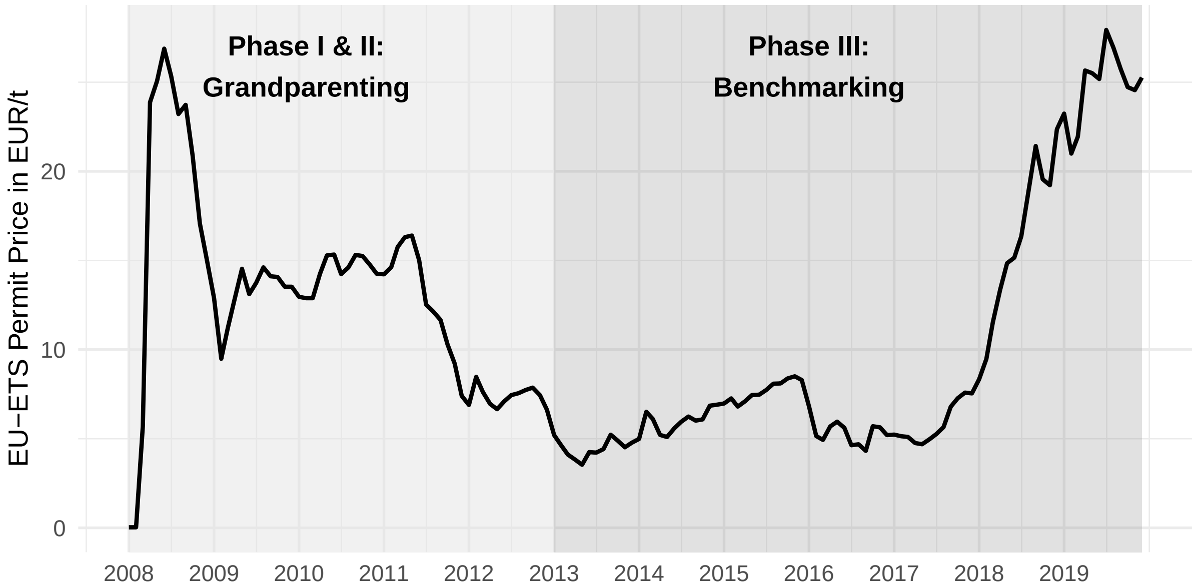

Figure A.1: Allowance price in the EU ETS

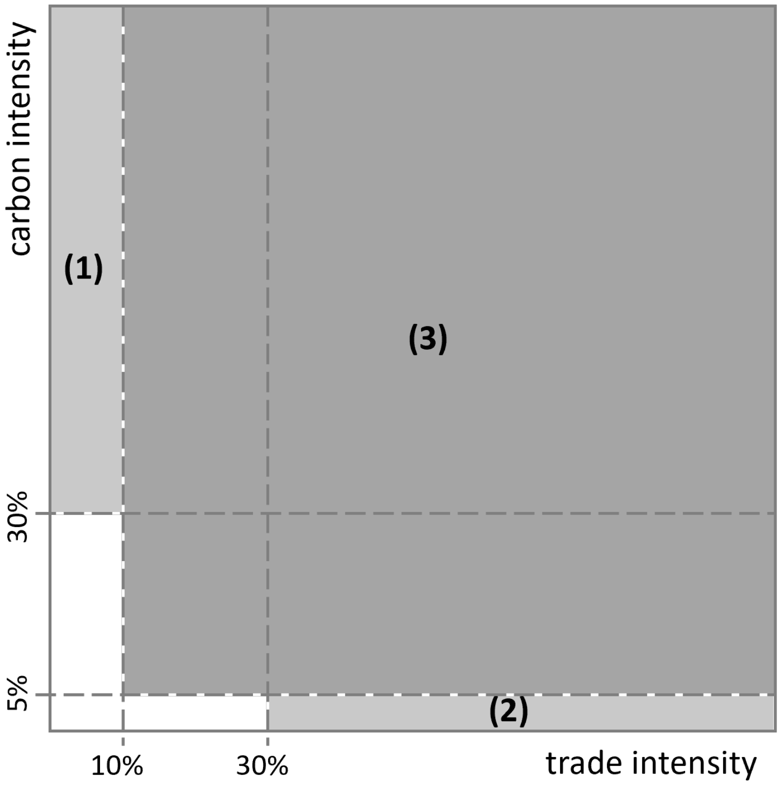

Figure A.2: Carbon leakage risk criteria

Note: If a sector falls into one of the shaded areas, then one of the three EU ETS carbon leakage risk criteria applies and the sector is included in the carbon leakage list and receives 100% of the benchmark free allocation. If the sector is in the non-shaded area, then it is not considered to be at a significant risk of carbon leakage and it only receives a declining fraction of the benchmark free allocation (80% in 2013 and 30% in 2020).

A.2 Covariate balance

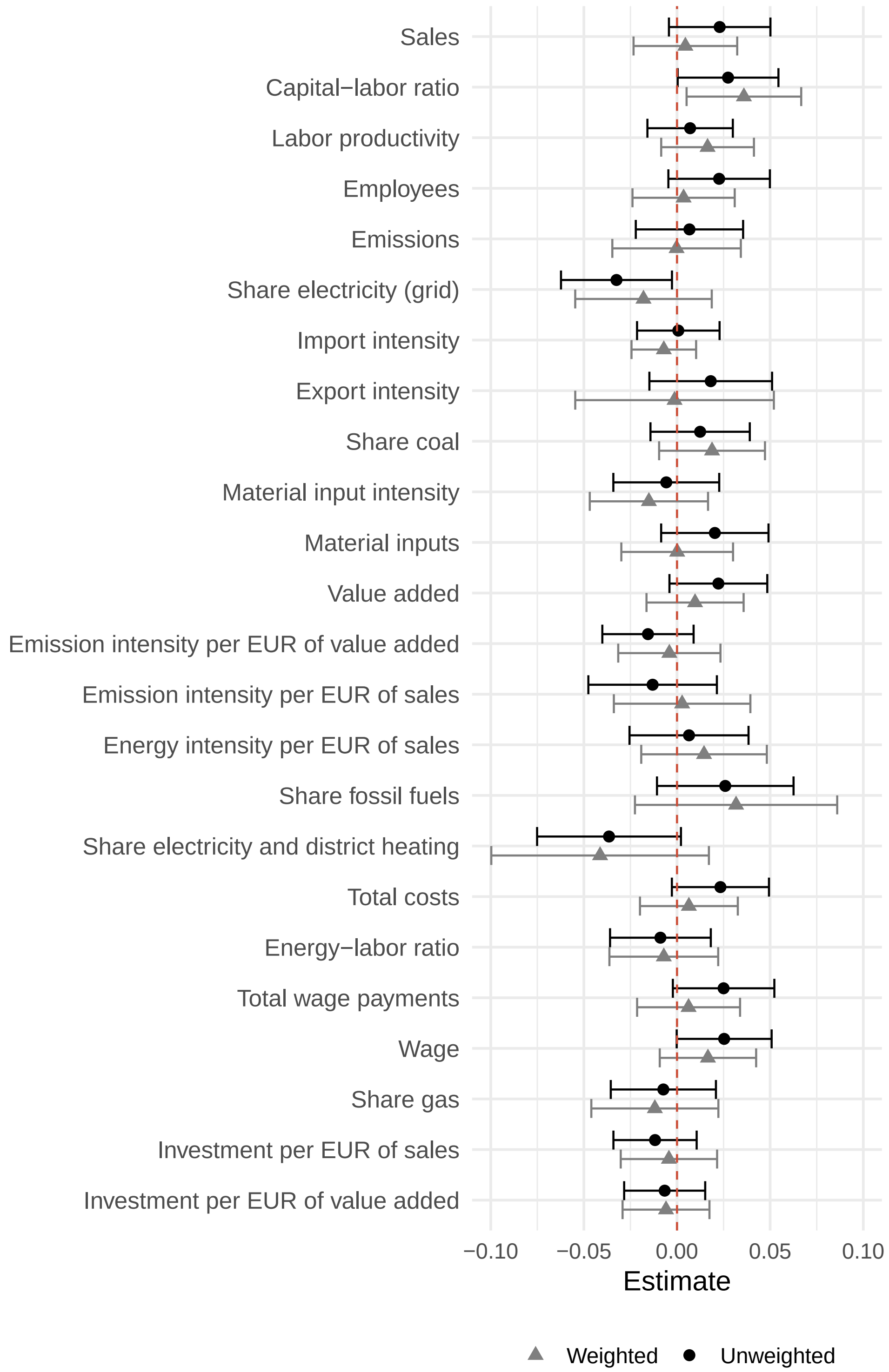

Figure A.3: Balance plot: Free allocation removal and covariates

Notes: The plot shows coefficients from regressing the treatment variable (benchmarking induced free allocation removal in percent) on various covariates. Each coefficient comes from a separate regression of the treatment on the respective covariate. All regressions include year fixed effects. To make coefficients comparable, the covariates have been standardized to have mean 0 and a standard deviation of 1. The horizontal bars represent 95% confidence interval and the black dots represent coefficient estimates from unweighted regressions, whereas the grey triangles represent coefficients from weighted regression with entropy balancing weights.

A.3 Event study estimates

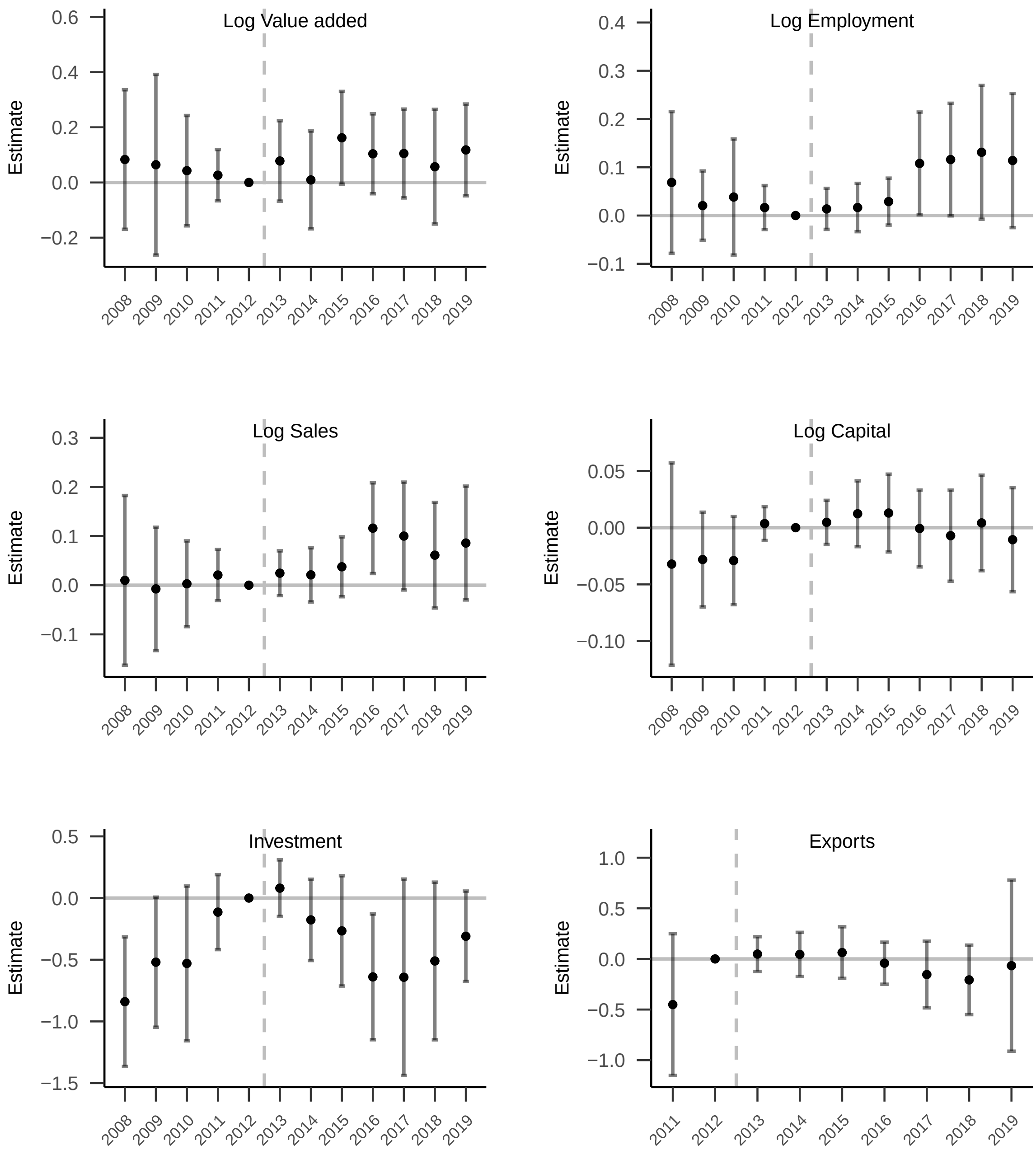

Figure A.4: Event study estimates on outcomes related to firms' competitiveness

Note: The point indicates the event study estimate according to specification (3) and the whiskers the corresponding 95% confidence interval based on standard errors clustered at the firm level. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: Aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for eligible for electricity price compensation industry, and the baseline production of industrial gases in a firms' energy consumption. The first four panels are estimated using a log-linear specification and the last three columns using the Pseudo-Poisson-Maximum-Likelihood estimator.

A.4 Effect Heterogeneity

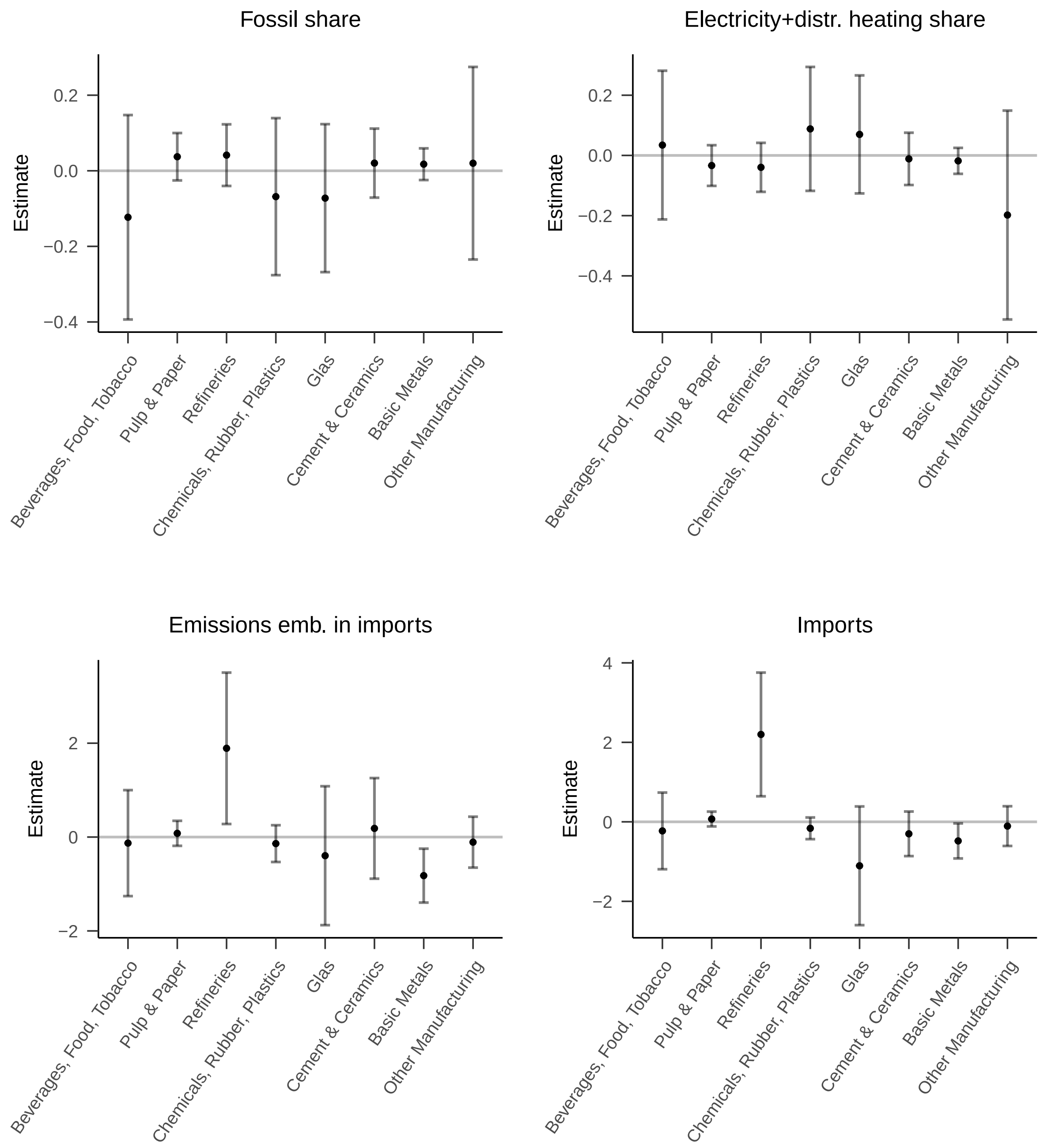

Figure A.5: Effects on fuel share and carbon leakage by sector

Notes: The point indicates the estimate for the corresponding sector (3) and the whiskers the corresponding 95% confidence interval based on standard errors clustered at the firm level. Estimates based on a regression with an interaction of sector dummies and the treatment. Emission and energy intensity measured in terms of value added. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: Aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for eligible for electricity price compensation industry, and the baseline production of industrial gases.

A.5 Robustness

	Log Emission intensity (sales)	Log energy intensity (sales)
Treatment	-0.193***	-0.0289
	(0.0741)	(0.111)
Observations	3007	3007

Table A.1: Alternative measures of emission intensity

Notes: Regressions of the dependent variables in columns on the change in free allowances between 2013 and 2012 (Treatment) according to specification (2). Standard errors (in parenthesis) are clustered at the firm-level. Fossil fuel share is the share of oil, natural and industrial gases, coal and waste in the total energetic use of energy carriers. The second panel shows the results for the share of electricity and district heating consumption in the total energetic use of energy carriers. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: aggregate sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk list, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for electricity price compensation industry, and firms' baseline production of industrial gases. First two panels are estimated with linear OLS, the second row with PPML.

	Log Emission intensity	Log Energy intensity	Fossil fuel share	Electr. & distr. heat. share	Imports	Emissions emb. in imports
Treatment	-0.184*	-0.0353	0.00124	-0.00650	-0.189	-0.296
	(0.0938)	(0.126)	(0.0268)	(0.0260)	(0.188)	(0.199)
Observations	3007	3007	3007	3007	2312	2312

Table A.2: Emission effects with 2-digit sector fixed effects

Notes: Regressions of the dependent variables in columns on the change in free allowances between 2013 and 2012 (Treatment) according to specification (2) similar to Table 2, but with the interaction of 2-digit NACE and year fixed effects instead of aggregate sector-fixed effects.. Standard errors (in parenthesis) are clustered at the firm-level. Emission intensity and energy intensity are measured as emissions and energetic use of energy carriers relative to sales. Fossil fuel share is the share of oil, natural and industrial gases, coal and waste in the total energetic use of energy carriers. The third column shows the results for the share of electricity and district heating consumption in the total energetic use of energy carriers. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: 2-digit NACE sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk list, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for electricity price compensation industry, and firms' baseline production of industrial gases. The first four columns are estimated using linear OLS and the last two with the Pseudo-Poisson-Maximum-Likelihood estimator.

	Log Value added	Log Employment	Log Sales	Log Capital	Investment	Exports
Treatment	0.0483	0.0403	0.0474	0.0173	0.0472	0.266
	(0.0821)	(0.0297)	(0.0455)	(0.0183)	(0.147)	(0.237)
Observations	3,007	3,007	3,007	3,007	3007	2312

Table A.3: Competitiveness effects with 2-digit sector fixed effects

Notes: Regressions of the dependent variables in columns on the change in free allowances between 2013 and 2012 (Treatment) according to specification (2) similar to Table 3, but with the interaction of 2-digit NACE and year fixed effects instead of aggregate sector-fixed effects. Standard errors (in parenthesis) are clustered at the firm-level. All regressions include firm-fixed effects and the interaction of the following variables with year-fixed effects: 2-digit NACE sector fixed effects, an indicator, whether a firm operates in a sector on the carbon leakage risk list, an indicator, whether a firm was affected by the change in the eligibility criteria for the national Special Equalization Scheme, the share of baseline electricity that is eligible for electricity price compensation industry, and firms' baseline production of industrial gases. The first four columns are estimated using linear OLS and the last two with the Pseudo-Poisson-Maximum-Likelihood estimator.