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Marie Alder, Eva Franzmeyer and Benjamin Hattemer

From Free to Fee: How Emission Permit Allocation Affects Firms

Tampere University

UNIVERSITY OF HELSINKI

VATT INSTITUTE FOR ECONOMIC RESEARCH

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From Free to Fee: How Emission Permit Allocation Affects Firms*

Marie Alder
European University Institute

Eva Franzmeyer
European University Institute

Benjamin Hattemer
University of Helsinki

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Abstract

This study provides new causal evidence on the firm-level effects of reducing free emission permits in emission trading systems. Using a difference-in-differences design, we exploit a reform that altered an eligibility threshold for free permit allocation. Receiving fewer free permits reduced emissions by more than 14 percent relative to firms that retained them. This reduction was accompanied by similar declines in revenue, employment, and assets. We develop a multi-product general equilibrium model that explains these patterns through a novel mechanism linking permit allocation to firms' decisions. Firms that receive fewer free emission permits terminate their least productive product lines, increasing the market share of the remaining ones. Higher expected profits then encourage earlier adoption of an efficiency-improving technology.

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Email: marie.alder@eui.eu, eva.franzmeyer@eui.eu and benjamin.hattemer@helsinki.fi

1 Introduction

This paper examines how the allocation of free emission permits affects firm outcomes under emissions trading systems (ETS). This question has become increasingly important as emissions regulated by ETS have expanded sharply in recent decades. At the same time, policymakers rely heavily on free permits to reduce the regulatory burden on regulated firms. Free permit allocation is theoretically attractive as the *independence property* suggests that the initial allocation of permits does not affect firms' emission outcomes (Montgomery, 1972). Yet, despite the central role of free permits in the practical design of ETS, empirical evidence on the independence of free permits is still scarce.

We provide new empirical evidence that fewer free emission permits decrease both firms' emissions and their economic activity. We combine administrative data on emissions from manufacturing firms regulated under the EU ETS with balance-sheet information. For identification, we exploit a reform that introduced a discrete eligibility threshold for free allocation. Below this threshold, firms lost a substantial share of their free permits. This natural experiment allows us to estimate the causal effect of free permit allocation on firm outcomes using a difference-in-differences design. Existing theoretical work on the independence property cannot explain the empirical results that we document. Therefore, we develop a multi-product general equilibrium model based on the structure of Melitz (2003). Our framework suggests a novel mechanism explaining the failure of the independence property.

We obtain three main findings. First, the reform-induced reduction in free emission permits leads to a substantial decline in emissions among treated firms. Second, the drop in emissions is accompanied by a decrease in economic activity of similar size. Third, we show in a model that reducing free permit allocation lowers the transfer received by the firm and triggers the exit of the least productive product lines, which reduces firm size and emissions.

The emissions response of treated firms is substantial and economically meaningful. Emissions fall immediately upon the announcement of the reform, and the effect amplifies during implementation as fewer free permits are allocated. Following the announcement, treated firms reduced verified emissions by about 9 percent relative to the control group. With the implementation, the effect increases to more than 14 percent. The effect of the reform is in the same order of magnitude as the emissions response documented for the initial introduction of the EU ETS when comparing regulated to unregulated firms (Colmer et al., 2025).

In addition to emissions, we examine firm-level balance-sheet outcomes that reflect the economic activity of firms, namely revenue, total assets, and employment. The pattern differs from the result on emissions. At the announcement of the reform, these measures remain broadly unchanged despite the decline in emissions. After the reform is implemented, firms' economic activity contracts sharply. This indicates that firms initially abate without shrinking and only reduce scale once the cut in free allocation is in place. Following implementation, revenue, employment, and total assets fall by more than 15, 11, and 10 percent, respectively, a magnitude comparable to the reduction in emissions.

Existing theoretical considerations cannot explain the patterns we observe in our empirical results. First, market frictions in the EU ETS are unlikely to explain a failure of the independence property. Existing work has typically implied that the independence property should hold in well-functioning permit markets like the EU ETS (Hahn and Stavins, 2011). Second, no existing explanation accounts for the two-stage response in which emissions fall at announcement while firm activity adjusts only at implementation. Therefore, our findings require a different interpretation of the effect of free permits on firm behavior.

To address this concern, we develop a multi-product general equilibrium model based on the structure of Melitz (2003). Firms operate a continuum of product lines that differ in productivity. At the product-line level, free permits do not affect emissions, optimal quantities, or equilibrium prices. This mirrors the benchmark logic behind the independence property, since the model features no adjustment along the intensive margin at the product-line level. Free permit allocation matters at the firm level because products are aggregated. A reduction in free permits raises the fixed cost of operating a given product line and induces the least productive lines to exit. Adjustment occurs along the extensive margin of product lines, which reduces firm-level revenue and input demand. This gives an explanation of the empirical observation at the implementation of the reform, where the emissions response is accompanied by a contraction in firm economic activity.

In a second step, the model allows product lines to purchase a technology that improves energy efficiency. Adoption entails a fixed cost, making it optimal only for sufficiently productive product lines. When the reform is announced, treated firms anticipate that the least productive product lines will become unprofitable and exit once the reduction in free allocation is implemented. At the same time, they anticipate that the remaining product lines will gain market share. This change in the expected profit of continuing product lines raises the return to investing in the efficiency-improving technology, making adoption optimal for a larger set of product lines already at the announcement. As a consequence, the model predicts a decline in emission intensity upon announcement, consistent with the empirical pattern in which emissions fall before firm scale adjusts.

This study provides the first causal evidence that free permit allocation affects emissions among regulated firms in a large ETS. Existing empirical work has not found such a link in a smaller ETS (Fowlie and Perloff, 2013). Zaklan (2023) also studies free permit allocation in the EU ETS, but focuses on the power sector, which covers a narrower part of the economy than manufacturing and features a single, homogeneous output. Our results contribute to the empirical literature testing the independence property by providing for the first time empirical evidence against it in a major ETS.

Our results on the economic activity of firms imply that increasing the stringency of an emissions trading system by reducing free permit allocation can introduce a trade-off between emissions reduction and the economic activity of firms. This evidence speaks to a growing literature on how environmental regulation shapes firm behavior (Greenstone et al., 2012; Kala et al., 2025; Ryan, 2012), and in particular to work studying ETS (Marin et al., 2018; Dechezleprêtre et al., 2023; Bayer and Aklin, 2020; Martin et al., 2016; Colmer et al., 2025; Janser et al., 2025; Löschel et al., 2019). Our results contribute to this literature by showing a clear trade-off between environmental and economic performance for firms regulated in ETS.

Our model provides a novel explanation for why the independence property may fail in general. It contributes to the literature that studies when, and for what reasons, the independence property breaks down (Hahn and Stavins, 2011). A key implication of our model is that the independence property can fail even in an environment without market frictions or non-cost-minimizing behavior. The breakdown instead arises from an extensive-margin adjustment within multi-product firms, where a change in free permit allocation affects which product lines operate in equilibrium. This perspective differs from the mechanism emphasized in Fowlie et al. (2016), where firms' behavior is shaped by future entitlements under the allocation rule. In our framework, exit is not driven by dynamic entitlement considerations, but by changes in the current profitability at the product-line level.

The remainder of this paper is structured as follows. Section 2 provides an overview of the EU ETS, with a particular emphasis on the allocation of free emission permits between the different phases of the EU ETS. Section 3 presents the data set we assemble, alongside descriptive insights. We detail the empirical strategy in Section 4, and Section 5 presents the results of the empirical analysis. Section 6 reports a set of robustness checks. Section 7 introduces the theoretical model and section 8 summarizes the findings and concludes.

2 Institutional Background and Policy Reform

2.1 Allowance Allocation in the EU ETS

The European Union Emissions Trading System (EU ETS) stands as the world's oldest emissions trading program, having been implemented in 2005. Today, it remains the largest carbon market in terms of value traded. The EU ETS regulates more than 12,000 installations across 31 countries - including all EU member states as well as Iceland, Liechtenstein, and Norway[1]. Regulation under the EU ETS takes place at the installation level, covering installations engaged in activities such as metal processing, refining, and other operations with high combustion capacity. Coverage is determined by activity-based capacity thresholds rather than explicit emissions limits; however, these thresholds generally correspond in practice to installations emitting around 25,000 tonnes of CO_2 equivalent per year. Installations below this level may therefore qualify for simplified reporting or optional exclusion, depending on Member State implementation (European Commission, 2010).[2]

The EU ETS was introduced to serve as a market-based mechanism for achieving emission reductions at minimal cost. However, concerns about the international competitiveness of EU industries led policymakers to allocate a large share of emission allowances for free. This strategy aimed to mitigate the *risk of carbon leakage*. This term describes the risk that emission-intensive production might shift to jurisdictions with laxer climate regulations. Additionally, free allowance [3] allocation enhances the political feasibility of the policy.

The EU ETS has evolved through four distinct phases. During Phase I (2005–2007) and Phase II (2008–2012), allowances were allocated almost entirely for free, and member states retained significant discretion in the distribution of allowances through National Allocation Plans. During this period, more than 90% of emission allowances were allocated free of charge, with only a small fraction - around 3% EU-wide - auctioned by a handful of Member States. Countries such as Germany, the United Kingdom, and the Netherlands conducted limited auctions during Phase II (2008–2012), but the vast majority of allowances were given out for free, whereby firms received allowances based on their historical emissions.

Phase III (2013–2020) marked a significant turning point in the design and governance of the EU ETS. The system underwent a comprehensive reform aimed at increasing harmonization, improving environmental effectiveness, and enhancing economic efficiency. One of the most important institutional changes was the move from decentralized National Allocation Plans to a single, EU-wide emissions cap (European Commission, 2025).

Another cornerstone of the reform was the establishment of auctioning as the default method of allowance allocation. This marked a substantial departure from the earlier reliance

[1]The UK was part of the EU ETS from its launch in 2005 until Brexit. As of January 1, 2021, the UK left the EU ETS and established its own UK ETS. Since then, Northern Ireland has been partially covered via the Ireland/Northern Ireland Protocol for electricity generation.

[2]Scope under the EU ETS is defined in Annex I of the Directive on the basis of specific activities and capacity thresholds, most commonly combustion units with a total rated thermal input above 20 MW. Article 27 allows for the optional exclusion of certain small emitters.

[3]In this paper, we use the terms *free emission permits* and *free allowances* interchangeably. Both refer to the number of EU ETS emission allowances a firm receives free of charge from the European Commission.

on free allocation by requiring firms to purchase a growing share of their emissions allowances. In 2013, more than 40% of the emissions cap was auctioned, and this share rose steadily over time, reaching approximately 57% by 2020 (European Commission, 2020). According to the European Commission (2025), the transition to auctioning increased transparency, ensured a more efficient allocation of allowances, and eliminated the windfall profits that had occurred when firms passed the opportunity cost of freely received allowances on to consumers.

Importantly for our analysis, a *carbon leakage list* was established to identify sectors deemed at significant risk of losing market share to foreign competitors. Installations operating in sectors on the carbon leakage list are eligible to receive 100% of their allowances for free, provided they meet the benchmarks. The carbon leakage mechanism represented a political compromise: it sought to protect Europe's energy-intensive industries from international competition while continuing the transition to a more market-based system of emissions pricing.

Phase IV (2021-2030) of the EU ETS retains the core design features introduced in Phase III but incorporates several adjustments to strengthen the system. The benchmark values used to determine free allocation were updated to reflect technological progress (European Commission, 2018a), and the Market Stability Reserve (MSR) — operational since 2019 — now plays a key role in addressing the surplus of allowances by automatically adjusting auction volumes (European Commission, 2021). Most relevant to our analysis, the criteria for identifying sectors eligible for carbon leakage protection have been revised and are now significantly more stringent, resulting in a narrower set of sectors receiving free allocation (European Commission, 2019). As shown in Figure 1, this change resulted in a drop in the share of free allowances for the affected sectors. The next section discusses the allocation of free allowances, with particular emphasis on the carbon leakage list.

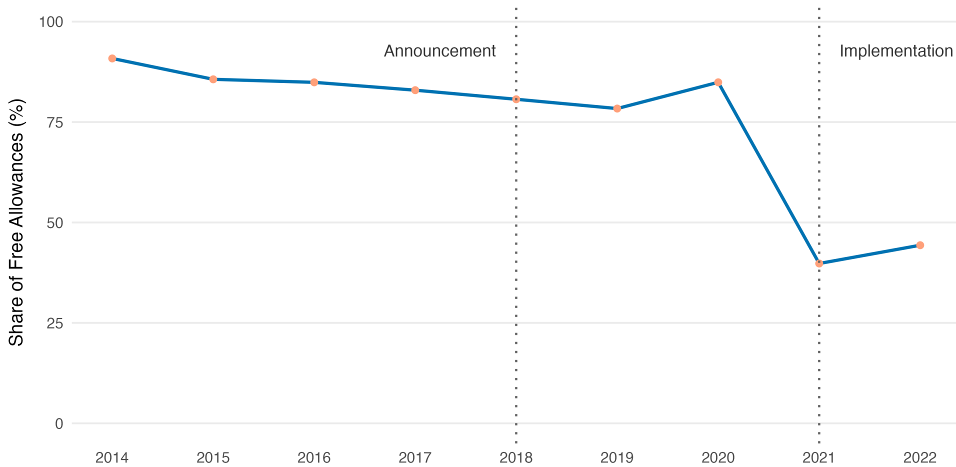
2.2 Free Allowance Allocation

In both Phase III and Phase IV of the EU ETS, free allowances are allocated at the installation level using a harmonized formula that links allocation to historical activity, emissions efficiency, and carbon leakage exposure (European Commission, 2024):

$$x_{ist} = B_s \cdot HAL_{i\bar{t}} \cdot R_t \cdot CLEF_{st} \tag{1}$$

Here, x_{ist} denotes the number of allowances allocated to installation i in sector s in year t. It is determined by four components: a sector-specific emissions benchmark B_s, the installation's historical activity level $HAL_{i\bar{t}}$, a time-varying reduction factor R_t that adjusts for the declining cap, and a carbon leakage exposure factor $CLEF_{st}$.

Figure 1: Share of Free Allowances for Affected Firms



Notes: This figure shows the average share of free allowances for firms affected by the change in the criteria for free allowances. The dotted lines indicate the announcement of the policy reform in May 2018 and its implementation in 2021. *Sources:* Authors' calculations based on EUTL data, Orbis data, and data from the European Commission (see Section 3 for more details on the data used).

The benchmark B_s reflects the average emissions per unit of output of the top 10% most efficient EU installations in each product category. These benchmarks are expressed in tons of CO_2 per unit of product and provide a uniform standard across the EU[4]. Therefore, an installation that exactly meets its sector's benchmark would receive free allowances equal to its expected emissions.

The term $HAL_{i\bar{t}}$ refers to the historical activity level of installation i, defined as the median annual output during a designated reference period[5]. This component anchors the allocation to the installation's past production, thereby decoupling it from current output choices and limiting incentives for overproduction. Phase IV introduced a dynamic allocation mechanism to account for significant changes in production over time. If the output deviates by more than ±15% from the historical baseline, future free allocations are adjusted proportionally.

The component R_t is a uniform cross-sectoral correction factor, also referred to as the cap-compliance factor. It ensures that the total volume of free allowances allocated to industrial installations remains within the maximum amount permitted under the overall emissions cap. After calculating the preliminary allocation for each installation - based on the product benchmark, historical activity, and carbon leakage status - the European Commission verifies

[4]Most benchmarks are product-based, but fallback values exist for heat and fuel consumption where product-level data are unavailable.

[5]The reference period was typically 2005–2008 for Phase III, and 2014–2018 for Phase IV.

whether the sum of free allowances exceeds the cap reserved per industry. If it does, a proportional adjustment is applied to all eligible installations by setting $R_t < 1$, thereby scaling down free allocations uniformly across sectors and Member States.

The final component, $CLEF_{st}$, is the carbon leakage exposure factor. It adjusts the level of free allocation based on whether a sector is deemed to be at significant risk of carbon leakage - that is, the risk that carbon costs could lead firms to relocate production outside the EU. Sectors included on the carbon leakage list receive their full allocation based on the benchmark and historical activity ($CLEF_{st} = 1$), while other sectors are subject to reduced allocation levels. In Phase III, sectors, excluded from the carbon leakage list, initially received 80% of their benchmarked allocation in 2013, with this share declining linearly to 30% by 2020. In Phase IV, this number was maintained through 2025. From 2026 onward, it is scheduled to decline gradually, reaching zero by 2030.

In both Phase III and Phase IV, inclusion on the carbon leakage list—and thus eligibility for full free allocation—is based primarily on a quantitative assessment along two dimensions: emission intensity and trade intensity. Together, these indicators are designed to identify sectors that are both exposed to international competition and for which carbon pricing represents a significant cost relative to value added. Both measures are computed by the European Commission using sector-level data. Sectors that exceed predefined thresholds in one or both dimensions are included in the carbon leakage list. These thresholds were substantially revised with the implementation of Phase IV of the EU ETS—referred to as *the reform* in this paper—and are described in more detail in the following section.

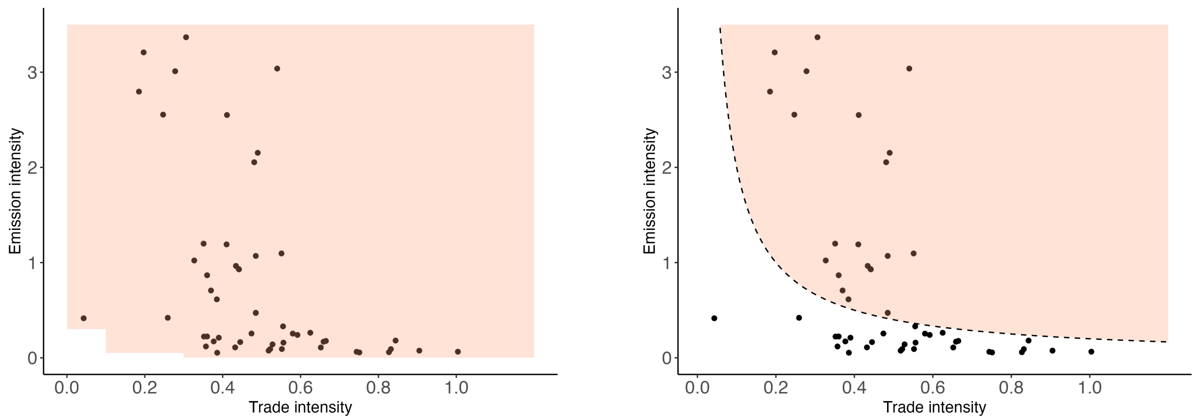
2.3 The Reform

In Phase III, the inclusion of a sector on the carbon leakage list was determined by a set of quantitative thresholds based on emission intensity and trade intensity. A sector qualified for full free allocation if it exhibited both a emission intensity of at least 5% and a trade intensity above 10%, or if it met either a emission intensity threshold of 30% or a trade intensity threshold of 30%.

The resulting set of eligible sectors is illustrated in Figure 2, panel (a). The shaded area reflects the combined application of the thresholds described above. Sectors falling within this area were included on the carbon leakage list and had a carbon leakage exposure factor of 100%. While the Phase III criteria succeeded in capturing sectors with significant exposure to international competition, they also resulted in a broad and inclusive carbon leakage list. Many sectors qualified for full free allocation despite exhibiting only a modest emission intensity. This generous approach diluted the targeting effectiveness of the policy and extended carbon leakage protection to sectors with relatively low vulnerability.

Figure 2: Quantitative Allocation Rule in Phase III and Phase IV

(a) Phase III (b) Phase IV



Notes: This figure shows the quantitative eligibility criteria for carbon leakage protection in Phase III (left) and Phase IV (right) of the EU ETS. Each dot represents a sector, plotted by its trade intensity (horizontal axis) and emission intensity (vertical axis). In Phase III, sectors qualified if they exceeded thresholds in either dimension (trade or cost), resulting in a large shaded area of eligibility. In Phase IV, eligibility was restricted to sectors with a composite indicator (trade intensity × emission intensity) greater than 0.2, represented by the area above the dotted curve. *Source:* European Commission.

Phase IV of the EU ETS introduced a more stringent definition of the carbon leakage risk[6]. Most notably, the three separate criteria used in Phase III were replaced by a single composite indicator: sectors are considered at risk if the product of their trade intensity and emission intensity exceeds 0.2. This change significantly reduced the number of eligible sectors, from around 175 under the previous list to 63. Panel (b) of Figure 2 shows the new combined factor: all sectors above the dotted line are on the carbon leakage list, while sectors below the line are no longer included on the carbon leakage list. The updated rule notably excludes sectors with high trade intensity but low emission intensity.

The revised list was published in May 2018 (European Commission, 2018b). At this point, firms and sectors could anticipate whether they would retain carbon leakage protection under the new regime. This timing plays a key role in our identification strategy, as discussed in Section 4.

With the introduction of Phase IV, two additional changes were made to the rules governing free allocation. First the methodology for calculating indirect emissions was adjusted to

[6] Additionally, the EU ETS legislation mandates that the European Commission periodically establishes a carbon leakage list, subject to approval by Member States and scrutiny by the European Parliament. The first list covered 2013–2014, the second extended until 2020 (based on updated industry data from 2009–2011, but with the same quantitative criteria), and the third list was drawn up in 2018 using the new composite indicator methodology for the entirety of the 2021–2030 period.

reflect the declining emission intensity of electricity generation. Second, a two-tier eligibility mechanism was introduced: sectors with a composite indicator between 0.15 and 0.20 could apply for inclusion via a qualitative assessment under Article 10b(2) of the ETS Directive. All sectors affected by these changes are excluded from our analysis.

3 Data and Summary Statistics

Emissions and Allowances We rely on publicly available data from the European Union Transaction Log (EUTL), which serves as the reporting and monitoring tool of the EU ETS. Specifically, we use a relational database constructed by Jan Abrell, which is based on the data from the EUTL.[7]

For emissions in each calendar year, ETS operators are required to monitor their emissions and prepare an emissions report. This report must be verified by an accredited verifier and submitted to the authority by 31 March of the following year. Then, by 30 September of the same year, operators must surrender the corresponding emission allowances in the Union Registry. The number of surrendered allowances must be at least equal to the verified emissions; otherwise, firms are subject to a monetary penalty.

The EUTL is the system that records the transfer of allowances between different actors. It provides detailed information on the compliance of installations, including verified emissions, as well as allocated and surrendered allowances for each year. We observe how many allowances were granted for free. Additional information includes the registry in which each installation is registered. For stationary installations[8], the registry corresponds to the country of location.

Jan Abrell provides a database that makes this information more accessible and additionally incorporates the NACE sector classification, which is essential for constructing the final panel dataset. The database provides annual observations for regulated installations from 2005 to 2022. We restrict the sample to installations for which the holding operator can be unambiguously identified.[9]

[7]The data can be accessed at https://www.euets.info/.

[8]The EU ETS regulates greenhouse gas emissions from both stationary installations and aircraft operators, but we focus exclusively on stationary installations.

[9]Following a reform of the EUTL in 2012–2013, operator holding accounts of type 120-0 were required to close and reopen as type 100-7. As a result, some installations are associated with two accounts over time in the EUTL. We apply two cleaning steps to ensure an unambiguous link. First, we retain only accounts that either remain open or were reported as closed after 2014. Second, we retain only accounts of type 100-7.

Carbon Leakage Classification The determination of a sector's carbon leakage status is pivotal for our analysis.[10] We obtain the carbon leakage lists from the European Commission and digitize them (European Commission, 2014; European Union, 2019). We also use trade and emission intensity metrics, together with the carbon leakage factor, to restrict the sample and improve comparability (European Commission, 2018b).

Firm-Level Data To analyze the impact of the reform on firm-level economic outcomes, we draw on data from the ORBIS database, which provides harmonized financial and operational information on firms across Europe. Specifically, we extract annual data on revenue, sales, employment, total assets, loans, and short-term debt.[11] Our analysis focuses on manufacturing firms located in EU member states.

To minimize the impact of reporting issues on our results, we restrict our sample to firms with non-missing and positive revenue, sales, total assets and number of employees.[12] Following Abrell et al. (2022), we exclude observations where allocations exceed verified emissions by a factor of ten. We also remove observations in which both verified emissions and allocations are zero, ensuring that installations which have ceased operations but are still listed in the EUTL are excluded. The sample is balanced based on the availability of emission data.

Descriptive Statistics The final dataset is an annual firm-level panel constructed for the period 2014–2022. We aggregate installation-level data from the EUTL to the firm level using ORBIS identifiers. The primary dataset used in the analysis is based on the four-digit NACE classification. Table 1 presents descriptive statistics for the control and treatment groups. On average, firms in the treatment group exhibit higher a revenue, higher sales, and employ more workers. However, as expected, they have lower emissions. Prior to the reform, both groups received more free allowances than their verified emissions. After the reform, this ratio declined for both groups, but more significantly for treated firms, which, at the time of the reform's implementation, received on average only 50% of their emissions in free allowances.

[10]If a firm comprises installations associated with different NACE codes, we assign the NACE code corresponding to the installation with the highest cumulative emissions over the period.

[11]These variables ensure sufficient coverage of the firms of interest in ORBIS.

[12]We acknowledge the limitations of the ORBIS database and mitigate their impact through our cleaning steps.

Table 1: Summary Statistics

	Control					Treatment				
	N	Mean	Min	Max	SD	N	Mean	Min	Max	SD
Financial Variables										
Revenue	2 246	580 901	389.68	18 750 395	1 230 604	884	2 495 986	3 548	92 654 000	9 031 196
Employees	2 246	944	1	104 023	3 676	884	8 097	4	413 811	38 656
Assets	2 246	502 534	290	11 383 277	1 100 323	884	3 434 308	5 716	126 285 000	13 641 825
Emissions										
Emissions	2 763	125 456	434	3 911 793	317 161	1 053	32 546	249	412 137	42 010
Free / Emissions (%, 2020)	307	121	0	664	98	116	106	0	760	85
Free / Emissions (%, 2021)	307	99	1	595	82	116	50	0	403	55

Notes: This table reports summary statistics for financial variables and emissions by treatment status. The control group includes firms in sectors that remained on the carbon leakage list after the reform; the treatment group includes firms in sectors that lost eligibility. Financial outcomes include firm-level revenue, number of employees and total assets. Emissions refer to verified CO_2 emissions. The last two rows show the average share of emissions covered by free allowances in 2020 and 2021, respectively, highlighting the shift in allocation resulting from the reform.

4 Empirical Strategy

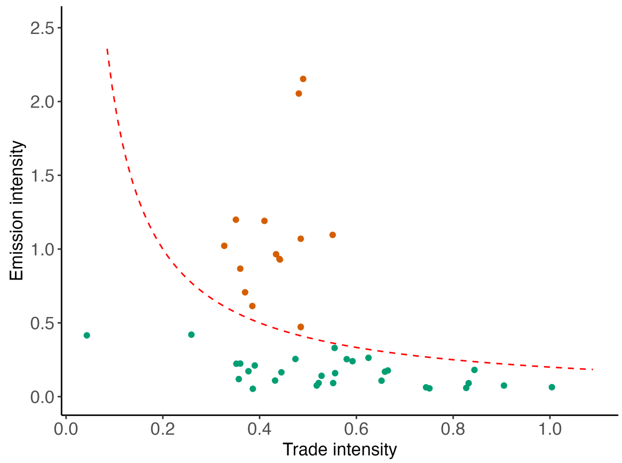
4.1 Research Design

In this paper, we aim to estimate the effect of free allowance allocation on firm outcomes. A key challenge is that the allocation of free allowances is typically not exogenous. As highlighted by Fowlie and Perloff (2013), free allowances are often allocated based on historical emissions, sectoral characteristics, and other factors that are themselves correlated with firms' current or future outcomes. Therefore, firms receiving more free allowances may differ systematically from those receiving fewer, in ways that are not fully observable to the researcher. Consequently, regressing emissions or revenue on the level of free allocation would likely yield biased estimates of the true causal effect.

To credibly identify this causal effect, one would ideally observe a setting in which free allowances are randomly assigned across otherwise comparable firms. In our setting, we exploit exogenous variation induced by the policy reform to the EU ETS, as described in detail in Section 2. As part of the 2018 revision, the European Commission introduced a new quantitative rule to determine which sectors are eligible to receive most of their historical emissions allowances free of charge. This reform led to a substantial tightening of the criteria, resulting in a sharp reduction in the number of sectors classified as *at risk of carbon leakage*.

Our identification strategy compares firms in sectors that lost carbon leakage status following the reform with firms in sectors that retained their status and continued to receive most of their allowances for free. Figure 3 illustrates this classification. All sectors depicted in the figure received predominantly free allowances in Phase III of the EU ETS. The redcolored sectors constitute the control group. They remain on the carbon leakage list and continue to benefit from near-full free allocation under Phase IV. The blue-colored sectors represent the treatment group. These sectors were removed from the carbon leakage list and received substantially fewer free allowances after the reform.

Figure 3: Selected Sample of Treatment and Control Units



Notes: This figure shows the selected sample of treated and control sectors based on their position relative to the Phase IV carbon leakage eligibility threshold. Each dot represents a sector, plotted by its trade intensity and emission intensity. The red dots indicate control sectors that remained eligible for near-full free allocation; the blue dots indicate treated sectors that lost eligibility under the reform. The dashed curve represents the threshold defined by the composite rule (trade intensity $\times$ emission intensity > 0.2). The sample is restricted to sectors near the cut-off to ensure comparability and common support.

Our main analysis is based on a balanced panel of firms observed continuously throughout the study period. This sample choice ensures that we capture effects within firms only, as firms that enter or exit the sample are excluded from the estimation. In our data set, firm entry and exit often involve inconsistent or incomplete reporting, and it is frequently unclear when a firm has truly ceased operations, introducing potential measurement error. Receiving fewer free allowances increases the total cost of firms. Therefore, firms may be more likely to exit and less to enter the market and the coefficient of our main specification can be interpreted as the lower bound of the total effect. By restricting our sample to a balanced panel, the interpretation of the dynamic difference-in-differences estimates is more transparent, given that it ensures that our estimation is not affected by potential measurement error and reflects changes in outcomes for a consistent set of firms over time.

4.2 Regression Analysis

We use a difference-in-differences (DiD) specification to estimate the average treatment effect of a reduction of free emission allowances on firms. The baseline regression takes the form:

$$\ln(y_{i,s,t}) = \alpha_i + \gamma_t + \rho D_{s,t} + \varepsilon_{i,s,t}, \tag{2}$$

where $\ln(y_{i,s,t})$ denotes the logarithm of the outcome variable for firm i in sector s at time t. The specification includes firm fixed effects α_i to control for time-invariant differences across firms and year fixed effects γ_t to capture common shocks affecting all firms in a given year. The treatment indicator $D_{s,t}$ equals one for treated sectors in post-reform years, and its coefficient ρ measures the Average Treatment Effect on the Treated (ATT). Standard errors are clustered at the sector level, which is the treatment level.

While the classical DiD provides a single average effect of the reform, it does not allow us to examine the timing and dynamics of the treatment. To address this, we also estimate a dynamic difference-in-differences model, which traces the evolution of treatment effects over time:

$$\ln(y_{i,s,t}) = \alpha_i + \gamma_t + \sum_{k=-m}^{M} \beta_k, \mathbb{1}[t - c_i = k] + \varepsilon_{i,s,t}. \tag{3}$$

Here, $\mathbb{1}[t - c_i = k]$ is an event-time indicator equal to one if year t is k years relative to the treatment year c_i of firm i, with the last pre-treatment year serving as the omitted baseline. The coefficients β_k measure the ATT in each relative year. Our implementation includes three pre-treatment years (2014–2016) and six post-treatment years (2018–2022). The parallel trends assumption requires that β_k for $k < 0$ are statistically indistinguishable from zero. Standard errors are again clustered at the sector level.

4.3 Identification

The identification of our difference-in-differences (DiD) framework relies on two key assumptions: the no anticipation and the parallel trends assumption (Roth et al., 2023). The no anticipation assumption requires that units do not adjust their behavior prior to treatment in response to future policy changes. We define the first post-treatment year as 2018. That is the year in which the revised carbon leakage list was announced. As detailed in Section 2, this announcement marked the earliest moment at which firms could have plausibly learned about their treatment status. We therefore use 2017 as our reference period.

The parallel trends assumption implies that in the absence of treatment, the treated and control groups would have followed similar trajectories in the outcome variables. Despite the fact that the parallel trend assumption can not be directly tested, our research design nevertheless speaks to the plausibility of this assumption.

Firms operating in sectors with very different emission intensities are likely to differ systematically in unobserved characteristics that may independently shape outcome trajectories. To mitigate this concern, we restrict the sample to sectors very close to the eligibility cutoff. By construction, sectors in this near-threshold window must be similar in the variables that determine treatment assignment. With this restriction, our identifying assumption is that, within this set of sectors close to the cutoff, treated and control firms would have exhibited parallel trends in the outcomes in the absence of the reform. Table B2 shows statistics of emission and trade intensity by treatment status before and after our sample restriction.

Still, several concerns remain. First, firms may have attempted to influence their treatment status. Direct manipulation of the underlying eligibility metrics is, however, unlikely in our setting. The relevant emissions and trade intensity values were constructed from historical data that predate the announcement of the Phase IV rule. This makes it impossible for firms to manipulate their emissions according to the rule. More broadly, the cutoff itself emerged from a policy process that, in principle, could be subject to lobbying. The simplicity and transparency of the rule nevertheless speak against substantial scope for strategic manipulation along the quantitative margin. Rather, any plausible influence would have operated through efforts to obtain a qualitative assessment or exception, which constituted a potentially viable lobbying strategy in the policy debate. Such qualitative adjustments applied only to a very small number of sectors, which we exclude from our estimation sample.

Second, broader macroeconomic shocks, such as the COVID-19 pandemic or the war in Ukraine, might affect treated and control sectors differently. We provide evidence on the robustness of our results to such shocks in Section 6.

Finally, the EUA prices increased substantially during our study period, as shown in Figure A1. Variation in permit prices can matter for our estimates through two channels. First, it can scale the treatment intensity. The monetary value of free allowances, and thus the implicit transfer generated by free allocation, is proportional to the contemporaneous EUA price. Therefore the effect of the reform we measure includes both, the quantity of free allowance allocation, as well as their value induced by the EUA price. Second, EUA prices may have an effect on firms emissions independent of the value of their free allowances. For our identification this becomes a threat if our treatment and control group are affected differently.

Changes in EUA prices during the sample period may affect treated and control firms differently for two reasons. First, exposure to the carbon price varies with baseline emissions intensity, so a given increase in the permit price represents a larger cost shock for firms that emit more per unit of activity. Second, treated and control firms operate in different sectors. Because sectors rely on different production technologies and input mixes, they may differ in their abatement elasticity. Thus, the same price change can induce different adjustments in emissions and production across groups.

Despite our sample restrictions, Figure 3 indicates that the sectors in the control group are more emission intensive and therefore more exposed to EUA prices than the sectors in the treatment group. If higher baseline exposure implies a stronger emissions response to rising EUA prices, emissions in the control group would fall more than emissions in the treatment group, even absent the reform. In that case, our difference-in-differences estimates would be biased toward zero, implying that the estimated treatment effect should be interpreted as a conservative estimate of the reform's total impact on emissions.

A final concern is that treated and control firms may differ in their abatement elasticities. High-emission manufacturing activities are often characterized as 'hard-to-abate', reflecting limited technological scope for deep emissions reductions in the short to medium run. Importantly, this characterization applies most strongly to the very high-intensity process industries that are far from the regulatory cutoffs, such as steel, cement, and primary aluminum (Change, 2022). These sectors are not represented in our analysis sample, as shown in Table B1. The industries included in our estimation sample exhibit substantially lower emission intensity than the canonical hard-to-abate sectors, reducing concerns that differences in technological abatement constraints mechanically drive the differential emissions responses we estimate.

5 Results

In Table 2, we present our main findings. We estimate Equation 2 that includes both the announcement and implementation dates. Column (1) shows that firms that lose a large share of their free allowances significantly reduce their emissions. After the reform announcement, firms receiving fewer free allowances reduced their emissions by almost 9%, compared with firms that continued to receive many allowances. Following the implementation of the 2021 reform, treated firms further reduced their emissions by more than 5%.

By contrast, column (2) shows that the revenue of treated firms remains unaffected by the announcement of the reform. At the implementation, however, revenue decreases by more than 16%. Similarly, the number of employees and total assets held by treated firms shrinks by more than 10% and 9%, respectively. At the announcement of the reform, total assets remain unaffected. Our estimation shows a 6% decline in the number of employees,

Table 2: Baseline Estimation

Dependent Variables:	Verified Emissions	Revenue	Employment	Assets
Variables				
Treatment × Post (2018)	-0.090***	-0.012	-0.066*	-0.012
	(0.026)	(0.038)	(0.038)	(0.029)
Treatment × Post (2021)	-0.053**	-0.161***	-0.051**	-0.091***
	(0.025)	(0.032)	(0.022)	(0.022)
Fixed-effects				
Firm FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Fit statistics				
Observations	3,816	3,124	3,124	3,124
R^2	0.97649	0.97554	0.97422	0.98312

Notes: This table presents difference-in-differences estimates of the effect of the reform on firm-level outcomes. The coefficients correspond to the average effect of the policy reform on treated firms when the reform is announced (2018) and implemented (2021). All variables are log-transformed and standard errors clustered at the sector level. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

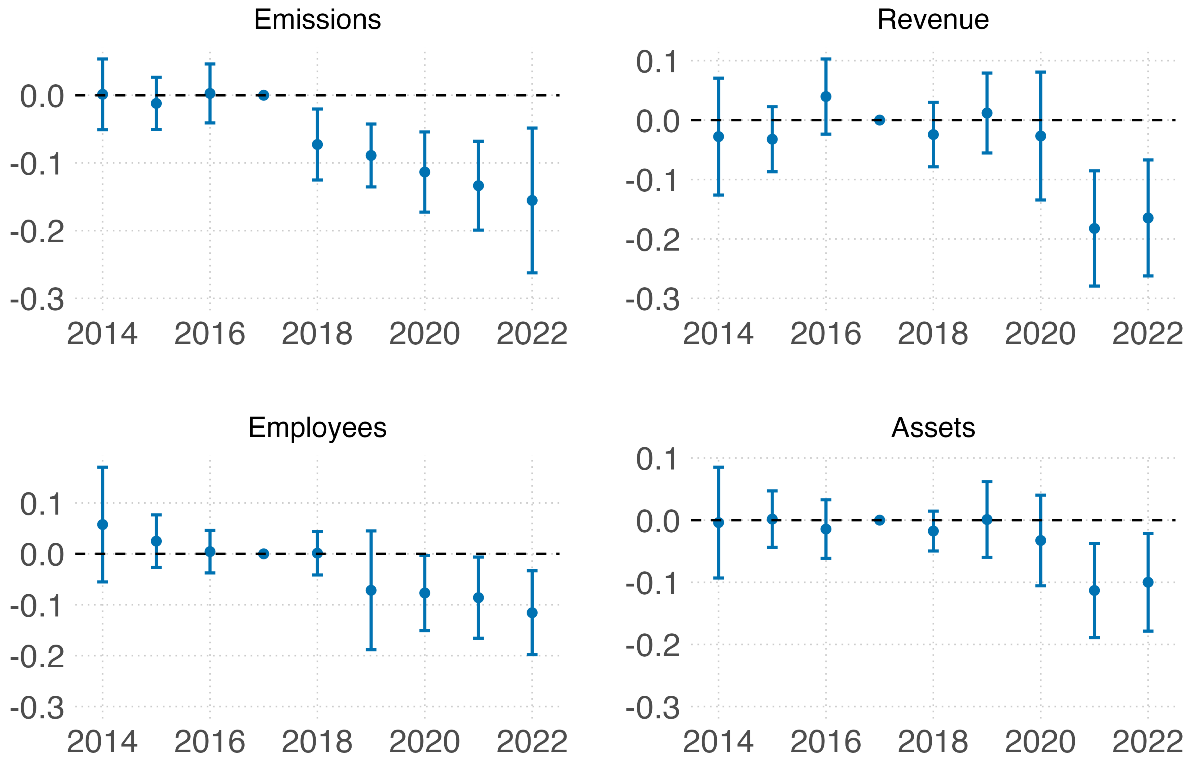
albeit with lower precision.

Figure 4 presents the dynamic difference-in-differences estimates from equation 3. During the pre-announcement period, the coefficients for all outcome variables are statistically indistinguishable from zero and show no systematic trend. While the parallel trends assumption is not directly testable, the flat and insignificant pre-announcement coefficients are consistent with it and lend credibility to the research design.

Our results show that firms' emissions respond to changes in the allocation of emission allowances. Empirical evidence on this relationship remains scarce, and existing work provides limited direct causal estimates of how free-allocation rules affect firms' emissions. Zaklan (2023) is one exception and does not find an effect of free allowance allocation on emissions for power producers in the EU ETS. Our results show that those results can not be generalized to the manufacturing industry, which covers a much larger share of the economy.

The estimated decline in emissions among treated firms is economically meaningful. The implied emissions response is comparable in magnitude to the estimated effects of the introduction of the EU ETS. Comparing firms included into the ETS with unregulated firms, Colmer et al. (2025) finds for manufacturing firms a reduction in emissions of 14% in phase I and 16% in phase II, without any effect on the economic activity of firms. By contrast, reducing free allowance allocation reduces both, emissions and firms' economic activity. This

Figure 4: Dynamic Difference-in-Difference Results



Notes: This figure shows dynamic treatment effects on firm-level economic outcomes using event-time indicators. Each panel reports coefficients from separate regressions with firm and year fixed effects. The outcomes are verified emissions, revenue, the number of employees, and total assets. All variables are log-transformed. The vertical bars represent 95% confidence intervals, with standard errors clustered at the sector level. Significant declines are observed after the policy announcement and particularly following the implementation year (2021), suggesting that the loss of free allowance allocation negatively affected firm performance across multiple dimensions.

suggests that the underlying mechanism by which emissions are decreased differs between the reform altering the allocation design and the introduction of the EU ETS.

A central motivation for allocating free allowances is to shield regulated firms from international competitive pressures. Accordingly, the implications of free allocation for trade flows have been extensively studied in the empirical literature (Grubb et al., 2022). Our setting is well suited to test whether the reduction in free allocation affected external adjustment margins. As shown in Appendix D, we find no effect of the reform on either imports or exports in treated sectors. These results indicate that the observed decline in firms' economic activity is not accompanied by a deterioration in international competitiveness, suggesting that the contraction operates through channels other than changes in trade performance.

Taken together, the reform reduced emissions by the same order of magnitude as the introduction of the EU ETS. In contrast to the introduction of the EU ETS, fewer free emission allowances not only reduced emissions but also had meaningful implications for firms' economic activity levels. The effects on firms are not accompanied with changing patterns in trade in treated sectors.

6 Robustness

To validate our empirical findings, we perform several robustness checks, focusing in particular on the parallel trends assumption and sensitivity to global events.

Matching Procedure We employ a matched difference-in-differences approach to validate our main results, following a methodology commonly used in related work (Colmer et al., 2025; Zaklan, 2023). For each variable, we use data from 2017, which is the year preceding the announcement of the policy reform. Firms are matched with replacement based on firm-level emission intensity[13] and total assets. These variables ensure comparability across firms in terms of technology and size and are also characterized by limited missing values, which helps preserve the sample size. Following Colmer et al. (2025), we implement a nearest-neighbour matching approach using the Mahalanobis distance. Under this approach, we use the full sample without imposing any restrictions on sector-specific emission intensity. Appendix C details the matched difference-in-differences methodology and shows that our results are robust to this alternative estimation strategy and to different specifications.

Industry Trends and Country-Time Fixed Effects Another potential concern of our empirical strategy is that sector-specific trends can be correlated with our treatment timing. To address this, we augment our baseline specification with sector-specific linear time trends, which relax the standard parallel-trends assumption by allowing outcomes within each sector to follow their own linear trajectories over time. In this specification, the treated–control comparison is identified from deviations from those sector trends after the reform. This directly addresses the concern that the effect we measure is driven by pre-existing, slow-moving sector dynamics that are correlated with treatment status. For example, differential technological progress and background decarbonisation trends, long-run demand shifts, gradual changes in global competition, or slow-moving differences in relative input-price sensitivity stemming from energy mix and factor substitutability. Table B3 shows that the results for

[13]Measured as the ratio of total verified emissions to revenue.

revenue and assets remain robust when allowing for sector-specific time trends. The results for emissions are also robust at the implementation date.

Further, we include country-time fixed effects to absorb confounders that vary at the country-year level. These fixed effects flexibly control for aggregate macroeconomic conditions such as GDP growth, unemployment, and inflation, as well as nationwide policy changes, including tax reforms, energy policies, and environmental regulation. They also account for country-level input price dynamics such as average electricity and gas prices and wage growth, and other country-level shocks, including exchange rate movements in non-euro countries. Table B4 shows that our results remain robust.

Major Economic Shocks Two major macroeconomic shocks during our sample period were the COVID-19 pandemic and Russia's invasion of Ukraine. Common shocks affecting all firms are absorbed by the year fixed effects. To the extent that these events interacted with slow-moving sectoral dynamics, our inclusion of sector-specific time trends further mitigates this concern. In addition, the country-time fixed effects capture differential national exposure to these shocks, for example, differences in reliance on Russian gas, heterogeneity in labor market institutions, and the availability and generosity of short-time work schemes. A residual concern is the presence of sector-specific shocks within country-years that are not well approximated by linear sector trends or fully absorbed by country-year effects. Reassuringly, Figure 4 shows no discrete changes in the first pandemic year (2020) or at the onset of the war (2022), suggesting that our estimates are not driven by these events. We also exclude sectors that are most plausibly affected by these shocks, and Figure A2 and A3 show that our results remain robust.

Common Support In our main analysis, we restrict the sample to sectors close to the eligibility threshold to improve comparability between treatment and control firms. Nevertheless, differences in observable characteristics across the two groups may remain. To address this concern, we implement an additional trimming procedure based on firms' pre-treatment averages of emissions, revenue, employment, and assets. Specifically, for each variable, we identify the group with the lower maximum value and exclude firms in the other group whose pretreatment average exceeds this maximum. This procedure enhances common support by eliminating observations that could never be observed in both groups, thereby ensuring that results are not driven by extreme values. Figure A4 illustrates the distributions before and after trimming, and Figure A5 the estimated treatment effects. The results remain largely unchanged, confirming that our findings are not sensitive to the lack of overlap in observables.

7 Mechanism

7.1 Independence of Free Permit Allocation

Our empirical results show a significant and non-trivial effect of a reduction in free allowances on firms' activity level. We observe a clear distinction between the announcement and implementation phases of the reform. At the announcement, verified emissions decline while the the economic indicators remain stable, consistent with firms using emissions more efficiently. At implementation, we observe an additional and economically meaningful adjustment margin. Firms shrink, leading to lower employment, fewer total assets, reduced revenues, and further declines in emissions. These findings directly imply that firm-level outcomes are not independent of the initial allocation of emission allowances. Our findings, therefore, provide direct empirical evidence against the independence property.

The independence property is based on the work of Coase (1960) and was formally applied to ETS by Montgomery (1972), who showed that transferable emission rights lead to a cost-effective allocation of abatement effort across firms. Crucially, this outcome does not depend on how permits are initially distributed. As long as the emissions cap is binding and permits are tradable, the marginal abatement cost will equalize across firms, regardless of whether permits are allocated for free or sold.

If free allowances do not affect the efficiency of ETS systems, governments can focus on setting the emissions cap while leaving decisions about permit allocation to legislators or political negotiations, without compromising the system's overall performance (Hahn and Stavins, 2011). This feature is particularly attractive to policymakers and has played a key role in the adoption of free allowance allocation under the EU ETS, as discussed in Section 2. This makes the question of whether the independence property holds in practice highly relevant for policymakers. Therefore, there is a long-standing debate about the market conditions under which the property is held in practice and whether they are given in the EU ETS.

Hahn and Stavins (2011) argue that the independence property should hold in the EU ETS. They outline several general reasons why the initial allocation of permits might affect outcomes.[14] For the EU ETS in particular, however, they conclude that these reasons are unlikely to undermine the independence property.

Yet, dynamics can break this result. Fowlie et al. (2016) challenges the independence property by showing that it may fail in a dynamic setting. In such contexts, receiving free

[14]These include, for example, transaction costs (Stavins, 1995), non-cost-minimizing behavior due to the endowment effect (Hortaçsu et al., 2019; Kahneman et al., 1990), market power and structure (Malueg and Yates, 2009), uncertainty (Baldursson and von der Fehr, 2004), and conditional allocation.

allowances creates a stream of future entitlements. Firms may be reluctant to exit or reduce output because doing so would forfeit this ongoing transfer. As a result, the allocation mechanism can distort dynamic decisions regarding investment, market participation, and firm exit.

Our framework provides an explanation for the failure of the independence property without assuming market frictions or non-cost-minimizing behavior. In contrast to Fowlie et al. (2016), firm's behavior is not influenced by future entitlements under the allocation rule. In our framework, adjustment occurs within multi-product firms along the extensive margin of product lines. Exit is not driven by dynamic entitlement considerations, but by current profitability at the product-line level.

7.2 Model

The model is based on the framework of Melitz (2003). In our model, each firm consists of a continuum of product lines. In the first step, we show that free allowances do not affect emissions, the optimal quantity, or the equilibrium price at the product-line level. This reflects the theoretical result of the independence property. However, at the aggregate firm level, the allocation design can have an effect. Specifically, fewer free allowances increase the fixed costs of a given product line, causing the least productive lines to exit the market. Firms therefore adjust along the extensive margin, leading to a reduction in firm-level revenue and input factor demand.

Second, in an extended version of the model, we allow firms to purchase a technology that improves energy-use efficiency. Firms anticipate the exit of the least productive product lines, resulting in higher revenues for the remaining lines after implementation. This strengthens incentives to invest in high energy-efficiency technology already at the announcement stage, thereby reducing emissions at that time.

This section is divided into two parts. First, we present the core model, outlining household behavior and production. We then describe how product-line production aggregates to the firm and economy levels. We close the model with the sections on the government as well as on entry and exit. Second, we analyze the policy intervention, examining the effects of reducing free allowances both at the time of implementation and at the time of announcement.

Households

The representative household maximizes utility choosing from different consumption goods subject to its budget constraint $PU = w\bar{L} + \Pi - T$, where labor earnings are given by $w\bar{L}$

with a fixed labor supply $\bar{L}$, along with firm profits Π and net of taxes T imposed by the government. The household does not save; it consumes its entire disposable income each period. The role of the government is described in more detail below.

The household derives utility from a composite consumption good that aggregates a continuum of differentiated varieties supplied by a large number of firms (N). Preferences over these goods are represented by a C.E.S. aggregator:

$$U = \left(\sum_{j=1}^{N} Q_j^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{where} \quad Q_j = \left(\int_{\Omega_j} q_j(\varphi)^{\frac{\sigma-1}{\sigma}} \, d\varphi \right)^{\frac{\sigma}{\sigma-1}}, \quad \sigma > \varepsilon > 1$$

where Q_j is the total quantity of a firm j, and each firm produces a continuum of goods or product lines[15]. φ represents the productivity level and Ω_j the mass of goods from firm j. These goods are substitutes, with an elasticity of substitution of $\sigma > 1$. Products from other firms are also substitutes with an elasticity of substitution of $\varepsilon > 1$. We assume that $\sigma > \varepsilon > 1$ to reflect the fact that purchasing a good from another firm may involve additional switching costs for consumers. For example, buying a personal computer is often tied to a specific operating system. Switching to a computer produced by another firm may require adapting to a different operating system, which lowers the effective elasticity of substitution relative to that between products offered by the same firm.

Dixit and Stiglitz (1977) showed that the set of varieties can be understood as an aggregate good $Q \equiv U$, which is associated with an aggregate price index:

$$P = \left(\sum_{j} P_j^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \quad \text{where} \quad P_j = \left(\int_{\Omega_j} p_j(\varphi)^{1-\sigma} d\varphi \right)^{\frac{1}{1-\sigma}} \tag{4}$$

where P_j is the firm level aggregate price index. Equation 4 allows us to derive the optimal consumption and expenditure decision on the firm level: $Q_j = Q \left(\frac{P_j}{P} \right)^{-\varepsilon}$ and $R_j = R \left(\frac{P_j}{P} \right)^{1-\varepsilon}$, where Q_j and R_j are the firm-level quantity and revenue, respectively. Q and R denote the corresponding aggregates for the entire economy. Similarly, within a firm j, the quantity and revenue of any given product line is $q_j(\varphi) = Q_j \left(\frac{p_j(\varphi)}{P_j} \right)^{-\sigma}$ and $r_j(\varphi) = R_j \left(\frac{p_j(\varphi)}{P_j} \right)^{1-\sigma}$.

[15] In this model, each product line produces one good.

Production

All firms and all product lines have the same production function which requires two factors, labor and energy. For a product line to operate, a fixed cost $F_j(\tau) = f_{\text{fix}} - x_j\tau$ has to be paid every period. f_{fix} represents general costs that are independent of the ETS, while x_j and τ are ETS-specific - namely, the number of free allowances allocated to a product line and the carbon price, respectively. Taken together, x_j and τ determine the value of the transfer. The technology which is used for production has constant returns to scale. The cost minimization problem of a product line is:

$$\min_{\ell_j, e_j} \; w\ell_j + (P_e + \tau)e_j + F_j(\tau) \quad \text{s.t.} \quad \varphi_j \, \ell_j^{\alpha} e_j^{1-\alpha} = 1$$

where ℓ_j is labor hired by a specific product line of a firm j and e_j is energy. The price of labor is given by the wage w and the price of energy by P_e. The wage w is taken as numéraire with fixed labor supply. The price of energy is the exogenous world price. For the carbon emissions associated with the energy used, τ has to be paid additionally. For simplicity, the conversion of energy units and carbon emissions is normalized to one. Product lines differ in their productivity level φ, but they all face the same production structure, input prices, and fixed costs F_j. A firm is a monopolist for each of its product lines and therefore maximizes profits, setting the price. Equivalently, minimizing costs on the product level allows us to calculate the unit cost of a given product line in firm j and to obtain the pricing rule:

$$c_u(\varphi) = \frac{1}{\varphi} \underbrace{\left(\frac{w}{\alpha}\right)^{\alpha} \left(\frac{P_e + \tau}{1-\alpha}\right)^{1-\alpha}}_{\equiv \Psi}, \qquad p_j(\varphi) = \underbrace{\frac{\sigma}{\sigma - 1}}_{\text{constant markup}} \frac{\Psi}{\varphi}$$

The expression $c_u(\varphi)$ shows again that the only difference between these product lines is the productivity φ. The term Ψ is the same for all products. Note that the optimal price of a product line is independent of the fixed cost F_j. This is in line with the independence property, since the intensive margin remains unaffected by changes in free allowances. Similar to atomistic firms in Melitz (2003), the ratios of any two product lines' quantity and revenue only depend on their relative productivity levels:

$$\frac{q_j(\varphi)}{q_j(\varphi')} = \left(\frac{\varphi}{\varphi'}\right)^{\sigma} \quad \frac{r_j(\varphi)}{r_j(\varphi')} = \left(\frac{\varphi}{\varphi'}\right)^{\sigma-1} \tag{5}$$

Aggregation

In our model, we distinguish between two types of aggregate variables. For firm j, the firm-level aggregates for price, revenue, quantity, and profit are denoted P_j, R_j, Q_j, and Π_j, respectively. The firm-level inputs are the labor L_j and energy E_j. The aggregates for the economy are defined as the sum of the same variables over all firms.

An equilibrium is characterized by a finite set of firms N. Each firm $j \in \{1, ..., N\}$ operates a mass M_j of product lines which differ in their productivity φ. $\mu(\varphi)$ is a distribution of productivity levels over the subset $(0, \infty)$, such that $\int_0^\infty \mu(\varphi) d\varphi = 1$. The distribution is the same for all firms. Similarly to Melitz (2003), we define $\tilde{\varphi}_j$ as a weighted average of the product line productivity levels φ: $\tilde{\varphi}_j \equiv \left[\int_0^\infty \varphi_j^{\sigma-1}\, \mu(\varphi)\, d\varphi\right]^{\frac{1}{\sigma-1}}$. $\tilde{\varphi}_j$ is independent of the number of product lines M_j in a firm. If each product line operated at productivity $\tilde{\varphi}_j$, the firm's price index would be unchanged relative to that implied by its actual distribution of productivities $\{\varphi(\varphi)\}_{\varphi \in \Omega_j}$. Accordingly, $\tilde{\varphi}_j$ summarizes the within-firm productivity distribution in P_j as a single sufficient statistic, conditional on M_j and common cost shifters. Under CES and constant markups, all firm-level aggregates decompose into the mass of active lines M_j and a single statistic of within-firm heterogeneity $\tilde{\varphi}_j$. As shown in Appendix E.1, firm-level aggregate quantity, revenue and profits are then given by:

$$P_j = M_j^{\frac{1}{1-\sigma}} p_j(\tilde{\varphi}) \qquad Q_j = M_j^{\frac{\sigma}{\sigma-1}} q_j(\tilde{\varphi}) \qquad R_j = M_j r_j(\tilde{\varphi}) \qquad \Pi_j = M_j \pi(\tilde{\varphi}_j) \tag{6}$$

By combining Equation 6 with the optimal expenditure decision, the ratios between the firm level aggregates and the economy aggregates can be calculated:

$$\frac{P_j}{P} = \frac{M_j^{-\frac{1}{\sigma-1}} \tilde{\varphi}_j^{-1}}{\left(\sum_{m=1}^N M_m^{\frac{\varepsilon-1}{\sigma-1}} \tilde{\varphi}_m^{\varepsilon-1}\right)^{-\frac{1}{\varepsilon-1}}} \qquad \frac{R_j}{R} = \left(\frac{P_j}{P}\right)^{1-\varepsilon} = \frac{M_j^{\frac{\varepsilon-1}{\sigma-1}} \tilde{\varphi}_j^{\varepsilon-1}}{\sum_{m=1}^N M_m^{\frac{\varepsilon-1}{\sigma-1}} \tilde{\varphi}_m^{\varepsilon-1}} \tag{7}$$

The firm level energy input for production E_j^p, and respectively for labor L_j^p can be derived by combining the pricing rule and the definition for revenue, $r(\varphi) = p(\varphi)q(\varphi)$, and making use of the fact that the expenditure for each input is constant. Taking the sum over all firms gives the economy-wide inputs used in production. The ratios of inputs of firm j relative to all inputs equal the ratio of revenue:

$$L_j^p = \frac{\alpha(\sigma-1)}{\sigma w} R_j \quad \text{and} \quad E_j^p = \frac{(1-\alpha)(\sigma-1)}{\sigma(P_e+\tau)} R_j \quad \Rightarrow \quad \frac{R_j}{R} = \frac{L_j^p}{L^p} = \frac{E_j^p}{E^p} \tag{8}$$

For the comparison with our empirical results, the relative price level $\frac{P_j}{P}$ of a treated firm

j is crucial, since it determines the relative revenue $\frac{R_j}{R}$ as well as the relative energy demand and thus emissions $\frac{E_j}{E}$. An increase in the firm level price relative to the economy-wide price index will decrease revenue and emissions, as implied by Equations 7 and 8.

In the following, we elaborate on the intuition underlying Equation 7 and highlight its form, which comprises two components in the numerator and two in the denominator. First, $M_j^{-\frac{1}{\sigma-1}}$ indicates that a larger mass of product lines within firm j decreases the relative price index. Since P_j represents the minimized costs of one unit of firm j's CES bundle, more varieties expand consumer options and make it cheaper to achieve the same utility. Second, $\tilde{\varphi}_j$ represents the weighted average productivity within firm j. The higher the average productivity $\tilde{\varphi}_j$, the lower the firm-level price index given the pricing rule.

The denominator can be interpreted as the top nest normalizer. It is the market-wide benchmark against which all firms compete. When any firm adds more product lines, this benchmark rises, which lowers the aggregate price index and slightly squeezes everyone else's shares. The same dynamic occurs if a firm improves the average productivity of its active lines. If all firms improve by the same margin, the benchmark rises proportionally, so relative shares are unchanged. More product lines within a firm (M_j larger) or higher average productivity ($\tilde{\varphi}$) decrease P_j and therefore P through its share. The exponent $\frac{\varepsilon-1}{\sigma-1}$ shows that within-firm substitutability (σ) dampens the benefit of adding varieties, while across-firm substitutability (ε) amplifies how those within-firm gains translate into market share.

Government

The government collects lump-sum taxes from households to finance its expenditures, which consists of allocation of free emission allowances. The fiscal cost of free allocation depends on the mass of product lines operated by each firm and on the number of allowances allocated per product line, x_j. At the same time, the government raises revenue from the sale of emission permits, amounting to $E^{\text{cap}}\tau$, where E^{cap} denotes the total emissions cap and τ is the permit price. In addition, the government collects a fixed cost component from each product line that is independent of free allowance allocation, given by $\sum_{j=1}^{N} M_j f_{\text{fix}}$. Overall, government net revenues are given by

$$T = \sum_{j=1}^{N} M_j x_j \tau - E^{\text{cap}}\tau - \sum_{j=1}^{N} M_j f_{\text{fix}}$$

Entry and Exit

There is an unbounded pool of prospective entrants of product lines into any given firm j. Prior to entry, those lines are identical and must pay a fixed cost $f_e > 0$. Note that the entry cost is the same for all product lines. After entry, product lines draw their initial productivity parameter φ_j from a distribution $g(\varphi)$ which has support over $(0, \infty)$ with a continuous cumulative distribution $G(\varphi)$. The distribution $g(\varphi)$ is common across firms.

After entry, a product line may immediately exit and not produce. If a product line produces, it faces a constant probability δ to receive a bad shock and exit. The value of the product line can then be expressed as $v_j(\varphi) = \max\left\{0, \frac{\pi_j(\varphi)}{\delta}\right\}$. Active product lines must have a positive profit. Thus, the lowest possible productivity level of active variants (hereafter cut-off level) yields a profit of zero: $v_j(\varphi_j^*) = 0 \iff \pi_j(\varphi_j^*) = 0$. Any product line that draws a productivity level $\varphi_j < \varphi_j^*$ will exit immediately. Similar to Melitz (2003), $\mu(\varphi_j)$ is the conditional distribution of $g(\varphi_j)$ on $[\varphi_j^*, \infty)$ and allows us to express the firm level average productivity level $\tilde{\varphi}_j$ as a function of the cutoff level: $\tilde{\varphi}_j(\varphi_j^*) = \left[\frac{1}{1 - G(\varphi_j^*)} \int_{\varphi_j^*}^{\infty} \varphi_j^{\sigma-1} g(\varphi_j)\, d\varphi_j\right]^{\frac{1}{\sigma-1}}$. Since the average productivity level $\tilde{\varphi}_j$ is completely determined by the cutoff productivity level φ_j^*, the average profit and revenue levels are as well. Using Equation 5 and the definition of average revenue $\bar{r}_j \equiv \int r_j(\varphi)\mu_j(\varphi)\, d\varphi$ and profits $\bar{\pi}_j \equiv \int_0^{\infty} \pi_j(\varphi)\mu_j(\varphi)\, d\varphi$, the zero cutoff profit (ZCP) condition is:

$$\pi(\varphi_j^*) = 0 \iff \frac{r(\varphi_j^*)}{\sigma} = F_j \iff \bar{\pi} = F_j \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-1} - 1\right] \tag{9}$$

where the ZCP is used to pin down the average product line profit $\bar{\pi}_j$. The expression $\bar{v}_j \equiv \int_{\varphi_j^*}^{\infty} v_j(\varphi)\, \mu_j(\varphi)\, d\varphi = \frac{1}{\delta}\bar{\pi}_j$ captures the present value of firm j's average profit flows and thus the average value of its product line. The expected stream of future profits must compensate for the entry cost $f_{e,j}$. Hence, the net value of entry is given by the value of the product line conditional on successful entry, weighted by the probability of entry, minus the fixed cost: $\frac{1-G(\varphi_j^*)}{\delta}\bar{\pi}_j - f_{e,j}$. If this value were negative, no product line would enter. In an equilibrium where entry is unrestricted, this value cannot be positive as well. Therefore, $v_{e,j} = 0$, which allows us to derive the free entry (FE) condition:

$$\bar{\pi}_j = \frac{\delta f_{e,j}}{1 - G(\varphi_j^*)} \tag{10}$$

The ZPC and FE retain the properties established in Melitz (2003), ensuring the existence and uniqueness of the equilibrium values φ_j^* and $\bar{\pi}_j$. For this equilibrium to be in a steady state, let n_j be the flow of new draws each period and δ the death probability. In steady state, inflows of successful entrants equal outflows of incumbents that die. The period-to-period change is: $M_{j,t+1} - M_{j,t} = n_{j,t}\left[1 - G(\varphi_j^*)\right] - \delta M_{j,t}$, where stationarity requires this change to be zero. Therefore, $M_j = \frac{n_j}{\delta}\left[1 - G(\varphi_j^*)\right]$. We use this expression together with Equations 10 and 6 to show that $\Pi_j = n_j f_{e,j}$. Thus, each period, firm j spends $n_j f_{e,j}$ on entry attempts, which equals in a stationary equilibrium the profits generated by the incumbent product lines Π_j. Due to the Cobb-Douglas production function, we know that the entry wage bill will be: $wL_j^e = \alpha\Pi_j$ and $E_j^e = \frac{1-\alpha}{P_e+\tau}\Pi_j$. The total inputs can then be expressed as:

$$L_j^{\text{tot}} = L_j^p + L_j^e = \frac{\alpha}{w}\left(\frac{\sigma-1}{\sigma}R_j + \Pi_j\right) \qquad E_j^{\text{tot}} = \frac{1-\alpha}{P_e+\tau}\left(\frac{\sigma-1}{\sigma}R_j + \Pi_j\right)$$

In the following two sections, we analyze the policy reform using this framework, beginning with a brief discussion on how the model maps to the institutional and empirical settings. The first section examines the effect of reducing free allowances for a subset of firms. The second one extends the model to allow firms to invest in emission-reducing technology, which enables us to assess the impact of the announcement of a reduction in free allowances.

Policy Implementation

In the EU ETS, the amount of free allowances is calculated at the installation level. Installations or sub-installations are closely related to our concept of product lines. The free allowances are allocated based on four different components, as shown in Equation 1. The benchmark B_s is sector-based and therefore identical across all product lines, under the assumption that each firm operates in only one sector. This assumption is well supported by our data.[16]

In our model, we abstract from the historical activity level $HAL_{i\bar{t}}$. As outlined in section 2, firms cannot manipulate their treatment status by decisions on their production or input demand. Consequently, firm size and past emissions do not play a strategic role in this context. We therefore abstract from this factor in the model and focus exclusively on identifying the effect of the reform. The time-varying reduction factor R_t affects all installations uniformly. Lastly, the carbon leakage factor, $CLEF_{st}$, is the key component of the allocation rule, as it constitutes our treatment. Under the data-consistent assumption that each firm operates within a single sector, all of a firm's product lines are exposed to the treatment in the same way. Hence, a firm is either treated or not.

In our empirical analysis, we compare firms that experience a reduction in free allowances in a difference-in-difference setting. Our main outcome variables are emissions, revenue, and other inputs in treated firms relative to control firms. The equivalent variables in the model

[16] In the our sample, 95% of firms operate installations in a single sector. Only a small share of firms (less than 2% of the sample) have more than one treatment status. In these cases, we assign firms to the sector corresponding to the installation (or group of installations) with the highest emissions. Our results are robust to excluding these firms.

are therefore the aggregated firm-level outcomes relative to the rest of the economy: $\frac{R_j}{R_{-j}}$, $\frac{E_j}{E_{-j}}$ and $\frac{L_j}{L_{-j}}$. As discussed above, those ratios depend on the relative price index of firm j: $\frac{P_j}{P_{-j}}$. In our model, free allowances decrease the fixed cost of every product line $F_j = f_{\text{fix}} - x_j\tau$. We assume that each product line in firm j receives the same amount of free allowances x_j. Therefore, to understand the effect of the implementation of the reform we take the derivative of the price index of firm j relative to all other firms $m \neq j$ with respect to the fixed cost F_j:

$$\frac{\partial}{\partial F_j} \ln\left(\frac{P_j}{P_{-j}}\right) = \left[\underbrace{-\frac{1}{\sigma-1}\frac{1}{M_j}\frac{\partial M_j}{\partial F_j}}_{\text{selection and entry}(+)} \underbrace{-\frac{1}{\tilde{\varphi}_j}\frac{\partial \tilde{\varphi}_j}{\partial F_j}}_{\text{composition }(-)} \right] (+\,\text{GE spillovers}) \tag{11}$$

where the GE spillovers are given by $-\sum_{m\neq j} \frac{R_m}{R}\left[-\frac{1}{\sigma-1}\frac{1}{M_m}\frac{\partial M_m}{\partial F_j} - \frac{1}{\tilde{\varphi}_m}\frac{\partial \tilde{\varphi}_m}{\partial F_j}\right]$. For the detailed steps of the derivation of the policy impact, see Appendix E.2. Overall, the fixed cost affects the relative price of firm j by jointly shaping the total mass of product lines, M_j, and the weighted average productivity of its operating lines, $\tilde{\varphi}_j$. It does so through three distinct channels - the selection channel, the entry-flow channel, and the composition channel.
M_j is affected through the entry-flow and the selection channel:

$$\frac{\partial M_j}{\partial F_j} = \underbrace{\frac{\partial n_j}{\partial F_j}\frac{1-G(\varphi_j^*)}{\delta}}_{\text{entry-flow}} - \underbrace{\frac{n_j}{\delta}\, g(\varphi_j^*)\,\frac{d\varphi_j^*}{dF_j}}_{\text{selection}} \tag{12}$$

The entry-flow channel captures the fact that higher fixed costs discourage the entrance of new product lines. Fewer attempts decrease the overall mass of product lines within firm j. In Equation 12, the channel is captured by a change in the entry-flow as a result of a change in fixed cost $\frac{\partial n_j}{\partial F_j} < 0$, multiplied with the probability that an entry is successful $1 - G(\varphi_j^*)$ and discounted by the death probability δ.

The selection channel arises because higher fixed costs raise the survival cutoff, $\frac{\partial \varphi_j^*}{\partial F_j} > 0$. Given density $g(\varphi_j^*)$ near this threshold, an increase in the cutoff reduces the survival rate and thus shrinks the mass of product lines M_j of firm j. Hence, both the entry-flow channel and the selection channel have a negative effect on M_j.

Finally, the composition channel describes the effect of fixed cost on the weighted average productivity $\tilde{\varphi}_j$:

$$\frac{\partial \tilde{\varphi}_j}{\partial F_j} = \underbrace{\frac{\partial \tilde{\varphi}_j}{\partial \varphi_j^*}}_{\text{truncation raises mean}} \underbrace{\frac{\partial \varphi_j^*}{dF_j}}_{\text{tougher cutoff}} > 0 \tag{13}$$

Here, a tighter survival cutoff for product lines $\left(\frac{\partial \varphi_j^*}{\partial F_j} > 0\right)$ increases the average productivity, since the least productive product lines leave the market. The term $\frac{\partial \tilde{\varphi}_j}{\partial \varphi_j^*} > 0$ captures the fact that the truncation of the distribution increases the weighted average productivity. In Appendix E.2, we show that, under a Pareto tail assumption, the sign of the effect of F_j on $\frac{P_j}{P_{-j}}$ is well defined. This result follows from establishing three intermediate results. First, assuming $\theta > \varepsilon - 1$, we characterize the sign of each of the three channels individually: the entry-flow channel $\left(\frac{\partial n_j}{\partial F_j} < 0\right)$, the selection channel $\left(\frac{d\varphi_j^*}{dF_j} > 0\right)$, and the composition channel $\left(\frac{\partial \tilde{\varphi}_j}{\partial F_j} > 0\right)$. Second, under the sufficient, but not necessary, condition $\theta > \sigma - 1$, the entry-flow and selection channels dominate the composition channel. Finally, we show that general equilibrium spillover effects amplify the direct effect.

Combing those three intermediate results, we conclude that the effect of a reduction in free allowances predicts an increase in relative prices $\frac{P_j}{P_{-j}}$ and therefore a reduction in revenue $\frac{R_j}{R_{-j}}$ and in the input factor demand $\frac{L_j^p}{L_{-j}^p}$ and $\frac{E_j^p}{E_{-j}^p}$.[17] Thus, the model predicts qualitatively exactly the response we observe in our empirical analyses at the implementation of the reform. In the next part, we discuss the announcement effect we observe only for emissions.

Announcement of Policy Change

In this section, we extend the model by allowing for an investment that increases the efficiency of product lines to use energy. Product lines can decide to pay a fixed cost K that grants them access to a technology shifting energy intensity $\eta > 0$. All derivations supplementary to this section are in Appendix E.3. With the high efficiency technology $\eta_h < \eta_l$, less energy is required for a unit of output and the cost minimization problem of product lines becomes:

$$\min_{\ell_j, e_j} \; w\ell_j + \eta(P_e + \tau)e_j \quad \text{s.t.} \quad \varphi_j \, \ell_j^{\alpha}(\eta e_j)^{1-\alpha} = 1.$$

[17] As we showed before, the shares of inputs used for production equals exactly the revenue share. This however may not hold for the total input demand, also including the input used for entry. In Appendix E.2 we show that the sign of the effect does not change when the effect on total inputs is used instead.

Then, the pricing rule becomes:

$$p(\eta;\varphi) = \frac{\sigma}{\sigma-1}\frac{\Psi(\eta)}{\varphi} \quad \text{and} \quad m \equiv \frac{\Psi(\eta_h)}{\Psi(\eta_\ell)} = \left(\frac{\eta_h}{\eta_\ell}\right)^{1-\alpha}$$

Now, each product line has two potential prices, p_h is the unit price when the high efficiency technology is adapted and p_l is the low efficiency equivalent. Using m, p_h can be expressed as a function of p_l: $p_h(\varphi) = m\, p_\ell(\varphi)$. Similarly, the revenue of a product line adopting the technology can be expressed as $r_h(\varphi) = m^{1-\sigma} r_\ell(\varphi)$. This allows us to calculate the increase in value of a product line that results from adopting the high efficiency technology:

$$\Delta v(\varphi) = \frac{\Delta\pi(\varphi)}{\delta} \qquad \text{where} \qquad \Delta\pi(\varphi) = \frac{1}{\sigma}(m^{1-\sigma}-1)r_\ell(\varphi) \tag{14}$$

A product line will adopt the high efficiency technology when the gain from adoption exceeds the cost: $\frac{\Delta\pi(\varphi)}{\delta} \geq K \iff \Delta\pi(\varphi) \geq \delta K$. Then, we obtain a unique productivity cutoff, above which a product line will adapt:

$$\varphi_j^A = \varphi_j^* \left[\frac{\sigma\delta K}{r_\ell(\varphi_j^*)(m^{1-\sigma}-1)}\right]^{1/(\sigma-1)} \tag{15}$$

Product lines with a productivity level $\varphi_j > \varphi_j^A$ will invest in the high-efficiency technology. The productivity threshold increases in the adoption cost δK, given that a higher present value of extra operating profits is needed to make the investment worthwhile, which requires a higher productivity. Larger $r(\varphi_j^*)$ increases every line's incremental profits due to the technology, decreasing the threshold. If the technology is weak ($m \to 1$), the threshold converges towards infinity, given that the gain of the technology adoption goes towards zero. Substitutability across varieties (σ) decreases the threshold, since it increases the demand response of having a lower price with the high efficiency technology $p_h < p_l$. Note that the threshold is independent of F_j, as we show in the Appendix.

To understand how the announcement of the reform affects treated firms, note first that the gain from adopting the high-efficiency technology depends on the revenue of the respective product line, as shown in Equation 15. The value of a technology is determined by the discounted stream of profit gains generated by lower production costs associated with the high-efficiency technology. This stream extends over an infinite horizon and is discounted using the constant death probability δ. The intuition behind the announcement effect is that the remaining product lines of the treated firm j anticipate higher future revenue. Their revenue is going to be higher, because they receive some share of the demand of those product lines exiting the market due to the higher fixed cost. The fact that the elasticity of substitution within firms is larger than between firms ($\sigma > \varepsilon > 1$) ensures that product lines of treated firm j are more affected than all other firms $m \neq j$.

Allowing for the revenue to change in the future, the value of a product line is based on $\Delta\pi_0$ in the current period and π_1 in all periods after:

$$\Delta v_0(\varphi) = \Delta\pi_0(\varphi) + (1-\delta)\Delta\pi_1(\varphi) + (1-\delta)^2\Delta\pi_1(\varphi) + \cdots = \Delta\pi_0(\varphi) + \frac{1-\delta}{\delta}\Delta\pi_1(\varphi).$$

This allows us to express the productivity cutoff, including the announcement effect, where $\frac{r_\ell^1(\varphi)}{r_\ell^0(\varphi)} \equiv \Phi_j$:

$$\varphi_{0,j}^A = \varphi_{0,j}^* \left[\frac{\sigma K}{r_\ell^0(\varphi^*)(m^{1-\sigma}-1)} \frac{1}{1+\frac{1-\delta}{\delta}\Phi_j} \right]^{\frac{1}{\sigma-1}} \tag{16}$$

Note that if the revenue remains the same for a given product line ($r_\ell^1(\varphi) = r_\ell^0(\varphi)$ and $\Phi_j = 1$), Equation 16 simplifies to 15. In the Appendix, we provide a detailed discussion on the components that affect Φ_j. When M_j, the number of product lines of firm j, decreases in $t = 1$, and households substitute those with other products in firm j, $\Phi_j > 1$. Then, the productivity cutoff above which a product line chooses to invest in the high efficiency technology decreases. A larger announcement factor Φ_j strictly lowers the adoption cutoff today: $\frac{\partial \varphi_{0,j}^A}{\partial F_{1,j}} < 0$. Therefore, if the revenue of the remaining product lines in firm j increases in $t = 1$, the productivity threshold above which product lines adopt the new technology decreases and more of them will adopt the efficient technology.

We are interested in the change in the productivity cutoff of the treated firm j relative to other firms $m \neq j$. If the treated firm j reacts more compared to other firms that keep their free allowances, our empirical findings that emissions decrease in treated firms already at the announcement of the reform are explained by the model. We show in the appendix that the relative change in the productivity cutoff can be expressed as:

$$\frac{\partial}{\partial F_j^1} \left(\frac{\varphi_{A,j}^0}{\varphi_{A,m}^0} \right) \Bigg|_{\Phi=1} = -\frac{1-\delta}{\sigma-1}(\sigma-\varepsilon) \left(\underbrace{\frac{1}{P_j^1}\frac{\partial P_j^1}{\partial F_j^1}}_{+} - \underbrace{\frac{1}{P_m^1}\frac{\partial P_m^1}{\partial F_j^1}}_{+} \right) \tag{17}$$

This equation shows that a higher fixed cost (F_j^1) for firm j in period $t = 1$ lowers the productivity cutoff in the treated firm j relative to other firms $m \neq j$. This effect consists of two channels. First, the within-firm demand increases for the product lines within firm j

that are remaining in the market. As discussed in the section about the implementation of the policy, the reform will increase the price level of firm j at $t = 1$, since higher fixed costs decrease the mass of product lines M_j, thereby increasing the firm-level price index P_j. The pricing rule of a product line is, however, independent of the fixed cost. Therefore, a given product line becomes cheaper relative to the firm-level price index P_j and thus has a higher revenue. That positive effect on a line's revenue has strength $\sigma - 1$.

Second, given the higher firm-level price index P_j, firm j will lose some revenue to other firms $m \neq j$. That negative effect on a line's revenue has strength $1-\varepsilon$. Taking both channels together, the within-firm substitution dominates since $\sigma-\varepsilon > 0$. The gap of the productivity cutoff grows proportionally to the gap between the within-firm and between-firm elasticity of substitution.

Conclusion

Taken together, this model rationalizes our empirical findings at the announcement as well as at the implementation of the reform. At the implementation of the reform, higher fixed costs decrease the mass of product lines of treated firms. This increases the price index of those firms compared to all other firms. Therefore, revenue and input demand fall. Due to the anticipation of a higher demand, the remaining product lines in the treated firm have a stronger incentive to invest in a cleaner technology than all other firms. Therefore, treated firms decrease their emissions relative to non-treated firms immediately upon announcement, which we also observe in our empirical analysis.

8 Conclusion

This paper provides new evidence on the role of free emission permits in emission trading systems. First, we exploit a major reform in the EU ETS with a sharp eligibility cutoff. By using a difference-in-differences design, we isolate the causal effect of losing access to free permit allocation on firm emissions and economic activity levels. Second, we develop a multi-product general equilibrium model, analyzing the relationship between free emission permits and firm outcomes in ETS.

We obtain three major results. First, emissions among treated firms substantially declined at the announcement and declined further at the implementation of the reform. Second, the drop in emissions is accompanied by a decline in the economic activity of firms only at the implementation. Third, our general equilibrium multi-product model shows that extensive margin adjustments on the product level can explain the patterns we observe.

A caveat of the empirical design is that identification is obtained from firms in sectors close to the eligibility cutoff. This strengthens our identification, but it also implies that the estimates are most informative for firms with relatively low emissions intensity. Despite having a large share the manufacturing industry in our sample, firms operating in sectors far from the cutoff are plausibly different along dimensions that matter for adjustment. Therefore, external validity beyond the near-threshold set of sectors may not be given.

These findings have direct implications for policy makers and for the design of emissions trading systems. They indicate that free permit allocation is not neutral, but affects both emissions and firms' economic activity. Free allocation can sustain product lines that would otherwise not operate, thereby increasing activity while lowering average productivity because less productive product lines remain in the market. This extensive-margin response also matters for environmental performance beyond the direct scale effect. By keeping marginal product lines active, free allocation can dampen the expansion of more productive product lines. It also weakens incentives for those lines to adopt cleaner technologies, which may reduce abatement and slow down technological upgrading.

Policymakers should be aware that the role of free allocation is broader than preserving international competitiveness. As free allowances are phased down in the coming years and the EU transitions toward a carbon border adjustment mechanism, these behavioral responses become part of the policy trade-offs. Accounting for the effects of free allocation on firms' scale and technology adoption is therefore important for designing and managing the transition.

These findings also point to two directions for future research. First, it is important to study the implications of free allocation for firms in highly emissions-intensive sectors. Our empirical setting is less informative about these sectors and additional evidence is needed to understand their response. At the same time, they account for a large share of regulated emissions, and free allocation is most prevalent in these activities. Given that this paper shows that free permits affect emissions, reductions in free allocation could be especially consequential in these industries.

Second, the adjustment mechanism suggested by the model should be tested in empirical settings that allow the predicted patterns to be observed more directly, for example, with data that observes the products firms produce, and technology adoption. Such evidence would help assess the external relevance of the mechanism and its ability to account for the magnitude of the effects.

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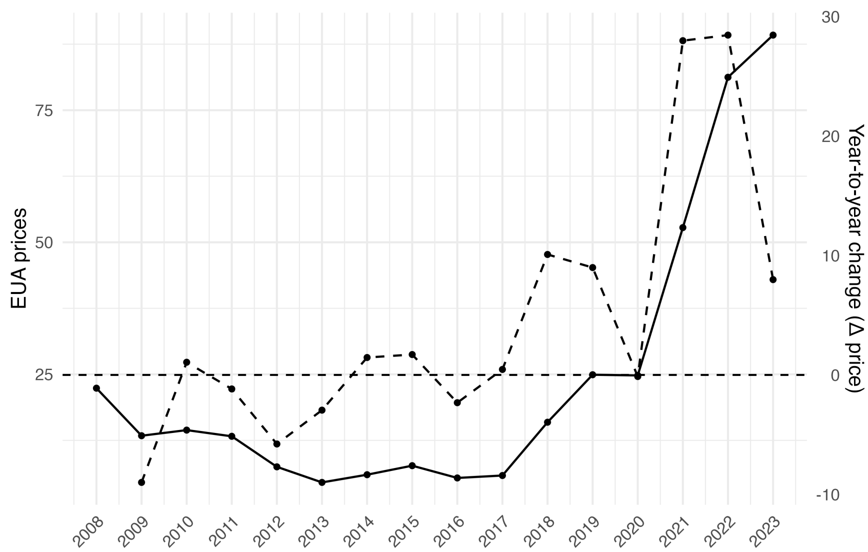
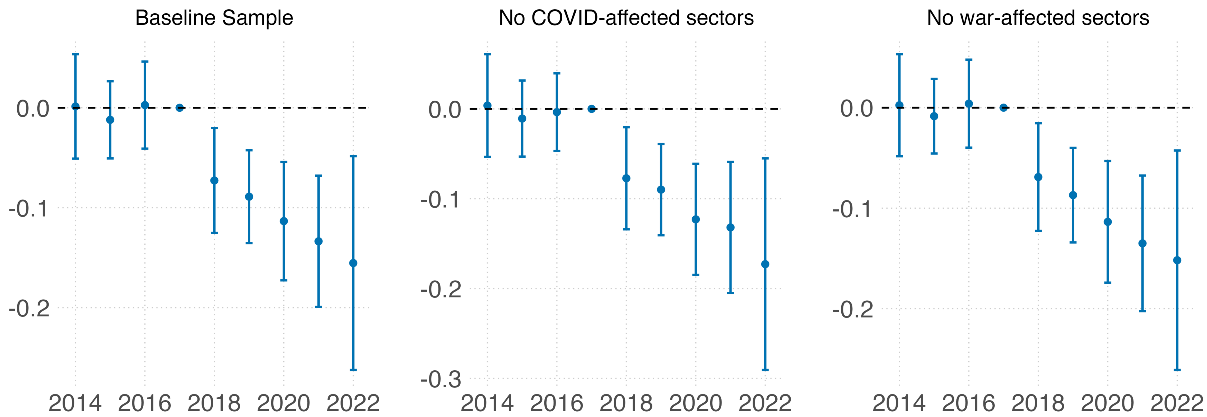
A Additional Figures

Figure A1: Evolution of EUA Prices



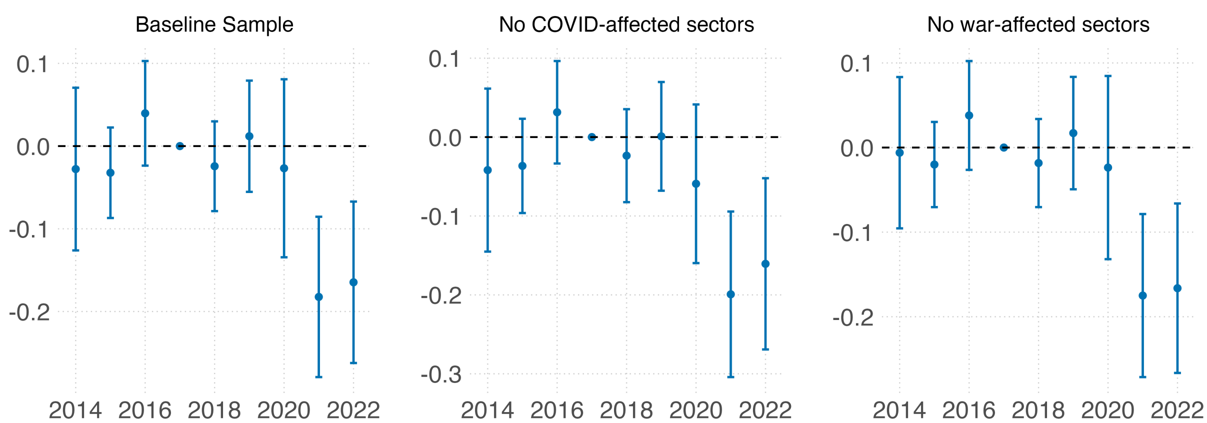
Notes: This figure plots the evolution of EUA prices. The dashed line shows the year-t-year changes in the prices. The EUA prices increased substantially during our study period. *Source:* European Energy Exchange.

Figure A2: Results on Emissions



Notes: This figure presents dynamic treatment effects on firm-level emissions across different sample restrictions. The left panel shows the baseline results using the full restricted sample. The middle panel excludes sectors strongly affected by COVID-19 (e.g., pharmaceutical manufacturing), while the right panel excludes sectors likely impacted by the war in Ukraine (e.g., arms and shipbuilding). Across all specifications, the estimated reductions in emissions after the reform remain robust, suggesting that the main results are not driven by sector-specific shocks related to the pandemic or geopolitical events.

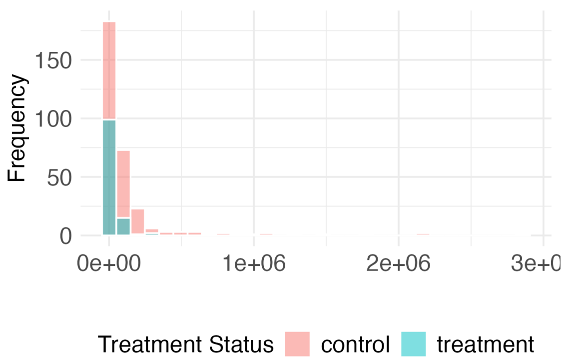
Figure A3: Results on Revenue



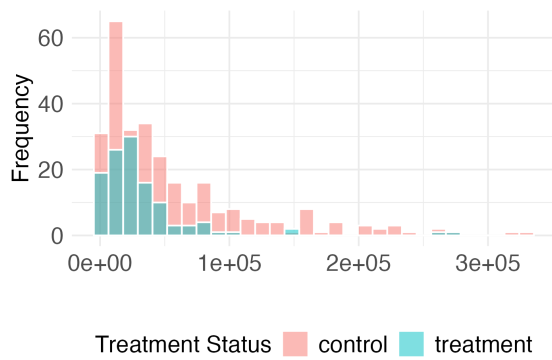
Notes: This figure shows dynamic treatment effects on firm-level revenue under different sample restrictions. The left panel displays results for the baseline sample. The middle panel excludes COVID-affected sectors (e.g., pharmaceutical manufacturing), and the right panel excludes war-affected sectors (e.g., arms and shipbuilding). The observed decline in revenue after 2021 remains consistent across specifications, indicating that the main economic effects are robust to excluding sectors with potential confounding shocks.

Figure A4: Descriptive Statistics on Common Support

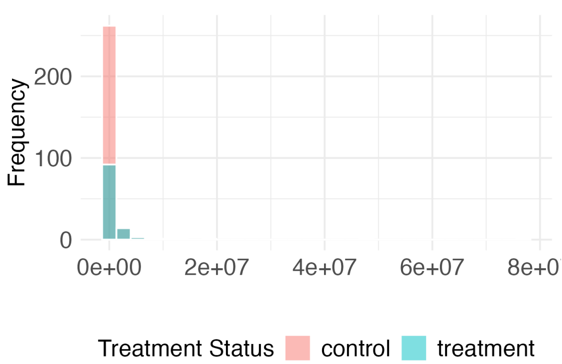
Before restriction **After restriction**



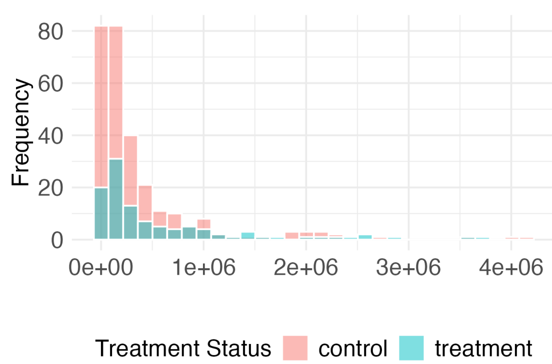
(a) Emissions



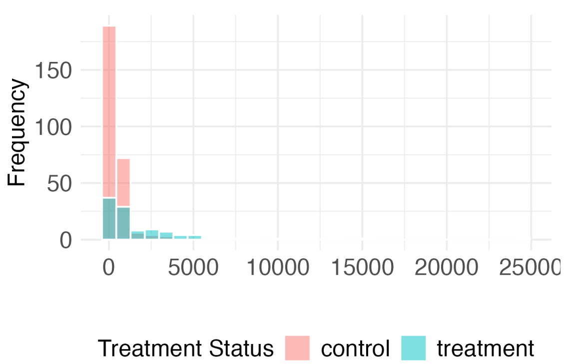
(b) Emissions



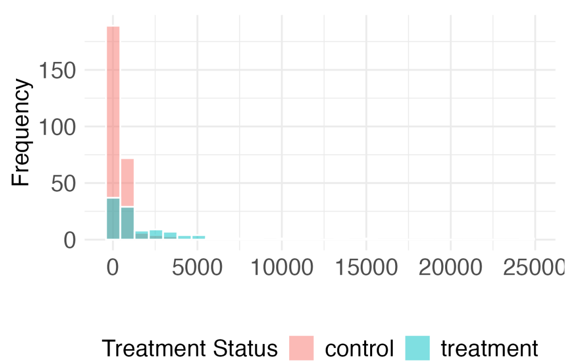
(c) Revenue



(d) Revenue



(e) Employment

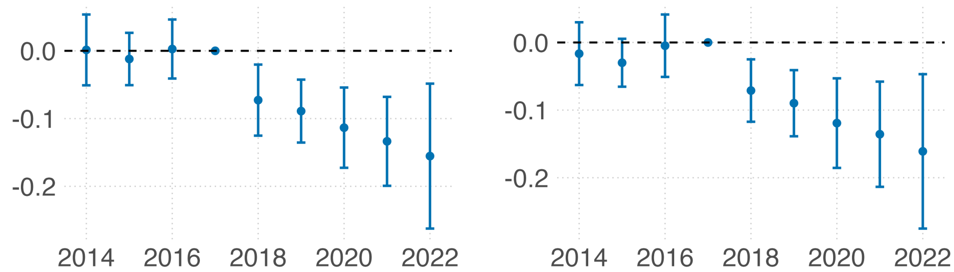


(f) Employment

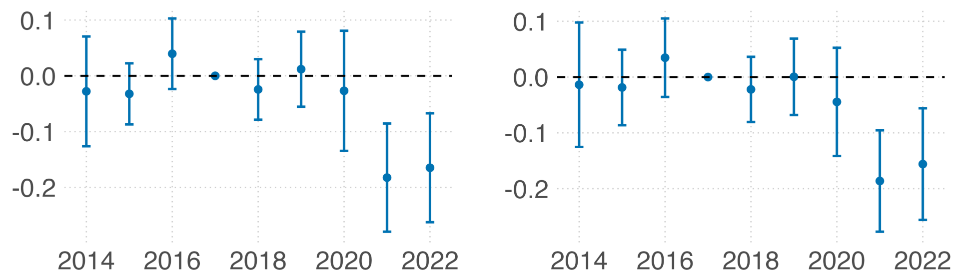
Notes: This figure shows the distribution of emissions, revenue, and employment by treatment status before and after applying a restriction on the sample. The restriction trims sectors with extreme values of emission intensity to improve comparability between treated (blue) and control (red) groups. After restricting the sample, the two groups exhibit greater overlap in the distributions, enhancing the credibility of the quasi-experimental design.

Figure A5: Baseline Results Before and After Restrictions on the Common Support

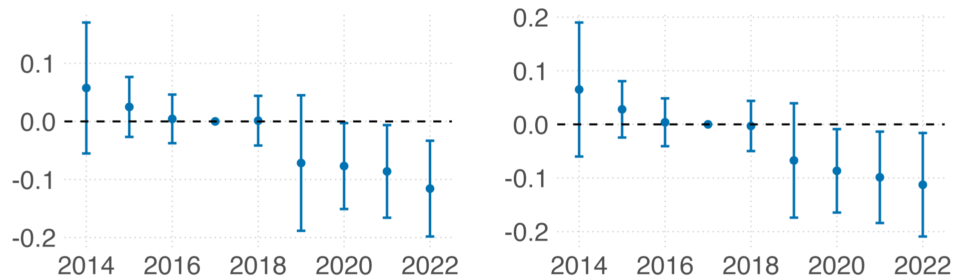
(a) Estimation on emissions, before (left panel) and after (right panel) restriction



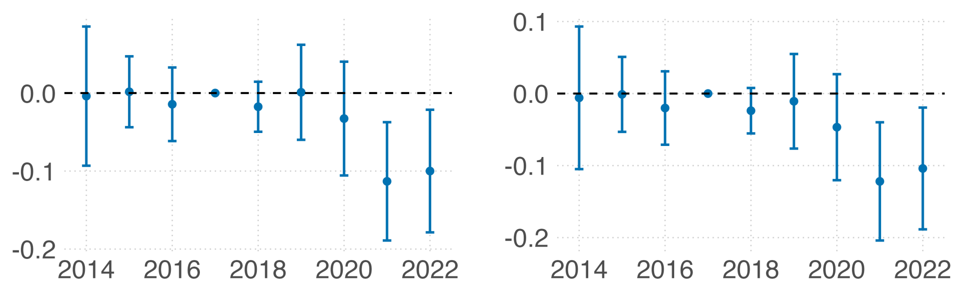
(b) Estimation on revenue, before (left panel) and after (right panel) restriction



(c) Estimation on employment, before (left panel) and after (right panel) restriction



(d) Estimation on assets, before (left panel) and after (right panel) restriction



Notes: This figure presents dynamic treatment effects on firm-level variables across different sample restrictions. The left panels shows the results using the full sample, while the right panels use the restricted sample. Variables are log-transformed and standard errors are clustered at the sector level. The estimated results remain robust across specifications, suggesting that the main results are not driven by the restriction of the sample.

B Additional Tables

Table B1: Classification of sectors according to their treatment status

Status	NACE	Description	In restricted sample
Control	C10.41	Manufacture of oils and fats	Yes
Control	C10.62	Manufacture of starches and starch products	**No**
Control	C10.81	Manufacture of sugar	**No**
Control	C11.06	Manufacture of malt	Yes
Control	C13.95	Manufacture of non-wovens and articles made from non-wovens, except apparel	Yes
Control	C17.11	Manufacture of pulp	Yes
Control	C17.12	Manufacture of paper and paperboard	**No**
Control	C19.10	Manufacture of coke oven products	**No**
Control	C19.20	Manufacture of refined petroleum products	**No**
Control	C20.12	Manufacture of dyes and pigments	Yes
Control	C20.13	Manufacture of other inorganic basic chemicals	**No**
Control	C20.14	Manufacture of other organic basic chemicals	Yes
Control	C20.15	Manufacture of fertilisers and nitrogen compounds	**No**
Control	C20.16	Manufacture of plastics in primary forms	Yes
Control	C20.17	Manufacture of synthetic rubber in primary forms	Yes
Control	C20.60	Manufacture of man-made fibres	Yes
Control	C23.11	Manufacture of flat glass	**No**
Control	C23.13	Manufacture of hollow glass	**No**
Control	C23.19	Manufacture and processing of other glass, including technical glassware	Yes
Control	C23.20	Manufacture of refractory products	Yes
Control	C23.31	Manufacture of ceramic tiles and flags	**No**
Control	C23.51	Manufacture of cement	**No**
Control	C23.52	Manufacture of lime and plaster	**No**
Control	C24.10	Manufacture of basic iron and steel and of ferro-alloys	**No**
Control	C24.20	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	Yes
Control	C24.31	Cold drawing of bars	Yes
Control	C24.42	Aluminium production	**No**
Control	C24.43	Lead, zinc and tin production	**No**
Control	C24.44	Copper production	Yes
Control	C24.51	Casting of iron	Yes
Treatment	C10.20	Processing and preserving of fish, crustaceans and molluscs	Yes
Treatment	C11.01	Distilling, rectifying and blending of spirits	Yes
Treatment	C11.04	Manufacture of other non-distilled fermented beverages	Yes
Treatment	C13.20	Weaving of textiles	Yes
Treatment	C13.91	Manufacture of knitted and crocheted fabrics	Yes
Treatment	C13.93	Manufacture of carpets and rugs	Yes
Treatment	C13.99	Manufacture of other textiles n.e.c.	Yes
Treatment	C16.29	Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials	Yes
Treatment	C20.20	Manufacture of pesticides and other agrochemical products	Yes
Treatment	C20.59	Manufacture of other chemical products n.e.c.	Yes
Treatment	C21.20	Manufacture of pharmaceutical preparations	Yes
Treatment	C22.11	Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	Yes
Treatment	C22.19	Manufacture of other rubber products	Yes
Treatment	C23.43	Manufacture of ceramic insulators and insulating fittings	Yes
Treatment	C23.44	Manufacture of other technical ceramic products	Yes
Treatment	C24.53	Casting of light metals	Yes
Treatment	C25.40	Manufacture of weapons and ammunition	Yes
Treatment	C26.11	Manufacture of electronic components	Yes
Treatment	C27.32	Manufacture of other electronic and electric wires and cables	Yes
Treatment	C27.40	Manufacture of electric lighting equipment	Yes
Treatment	C27.51	Manufacture of electric domestic appliances	Yes
Treatment	C27.90	Manufacture of other electrical equipment	Yes
Treatment	C28.11	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	Yes
Treatment	C28.13	Manufacture of other pumps and compressors	Yes
Treatment	C28.15	Manufacture of bearings, gears, gearing and driving elements	Yes
Treatment	C28.30	Manufacture of agricultural and forestry machinery	Yes
Treatment	C28.91	Manufacture of machinery for metallurgy	Yes
Treatment	C28.94	Manufacture of machinery for textile, apparel and leather production	Yes
Treatment	C30.11	Building of ships and floating structures	Yes
Treatment	C30.30	Manufacture of air and spacecraft and related machinery	Yes

Table B2: Summary of Emission Intensity and Trade Intensity by Treatment Status

Variable	Status	Mean	Median	Max	Min
Panel A: Before Restriction					
Emission Intensity	Control	6.05	3.01	24.22	0.47
	Treatment	0.18	0.18	0.42	0.05
Trade Intensity	Control	0.31	0.28	1.09	0.05
	Treatment	0.61	0.58	1.00	0.04
Panel B: After Restriction					
Emission Intensity	Control	1.45	1.20	2.15	0.47
	Treatment	0.18	0.18	0.42	0.05
Trade Intensity	Control	0.45	0.48	0.55	0.33
	Treatment	0.61	0.58	1.00	0.04

Notes: This table reports summary statistics for emission intensity and trade intensity across treatment and control groups. Treated sectors—those that lost eligibility for free allocation—display substantially lower emission intensity and higher trade intensity than control sectors, consistent with the reform's objective of concentrating protection on sectors with both high emission cost exposure and high trade exposure. The limited overlap in emission intensity between the two groups motivates the sample restriction applied in the main analysis to improve comparability. Panel A presents statistics for the full sample prior to the restriction, while Panel B reports statistics for the restricted sample. The restriction markedly narrows differences in emission intensity between treatment and control sectors.

Table B3: Baseline Results with Industry Trends

Dependent Variables:	Verified Emissions	Revenue	Employees	Assets
Model:	(1)	(2)	(3)	(4)
Variables				
Treatment × Post (2018)	-0.0681**	-0.0400	0.0177	-0.0024
	(0.0293)	(0.0350)	(0.0395)	(0.0198)
Treatment × Post (2021)	-0.0374	-0.1856***	0.0098	-0.0803***
	(0.0273)	(0.0447)	(0.0369)	(0.0227)
Fixed-effects				
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Varying Slopes				
Industry	Yes	Yes	Yes	Yes
Fit statistics				
Observations	3,816	3,124	3,124	3,124
R^2	0.97776	0.97711	0.97617	0.98500
Within R^2	0.00114	0.00802	5.8×10^{-5}	0.00263

Notes: This table presents difference-in-differences estimates of the effect of the reform on firm-level outcomes. The coefficients correspond to the average effect of the policy reform on treated firms when the reform is announced (2018) and implemented (2021). All variables are log-transformed and standard errors clustered at the sector level. We include industry-specific trends. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

Table B4: Baseline Results with Country-Time Fixed Effects

Dependent Variables:	Verified Emissions	Revenue	Employees	Assets
Model:	(1)	(2)	(3)	(4)
Variables				
Treatment x Post (2018)	-0.0828***	-0.0040	-0.0498	-0.0031
	(0.0278)	(0.0430)	(0.0358)	(0.0295)
Treatment x Post (2021)	-0.0560**	-0.1825***	-0.0486**	-0.0946***
	(0.0240)	(0.0313)	(0.0211)	(0.0227)
Fixed-effects				
Firm FE	Yes	Yes	Yes	Yes
Country x Time FE	Yes	Yes	Yes	Yes
Fit statistics				
Observations	3,789	3,094	3,094	3,094
R^2	0.97770	0.97674	0.97666	0.98400
Within R^2	0.01330	0.01681	0.00441	0.00675

Notes: This table presents difference-in-differences estimates of the effect of the reform on firm-level outcomes. The coefficients correspond to the average effect of the policy reform on treated firms when the reform is announced (2018) and implemented (2021). All variables are log-transformed and standard errors clustered at the sector level. We include firm fixed effects and country-time fixed effects. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

C Matching Procedure

We employ a direct matching procedure to validate our main results. For each variable, we use data from 2017, the year preceding the announcement of the policy reform. Firms are matched with replacement based on firm-level emission intensity[18] and total assets. These variables ensure comparability across firms in terms of technology and size and are also characterized by limited missing values, which helps preserve the sample size. Following Colmer et al. (2025), we implement a nearest-neighbour matching approach using the Mahalanobis distance.

Panel A of Table C5 reports coefficients measuring differences in outcome variables between treatment and control firms in 2017. Panel B presents the corresponding average differences for matched treatment and control firms. These differences are reduced across all variables and become statistically insignificant for revenue, assets, and sectoral emission intensity, indicating an improvement in common support between regulated and unregulated firms.

Table C5: Pre- and Post-Match Differences

Panel A: Pre-Match difference

	Emissions	Revenue	Employees	Assets	Emission Intensity
full sample	-1.232***	0.955***	1.250***	0.983***	-5.864***
	(0.103)	(0.181)	(0.176)	(0.187)	(0.188)
Observations	1346	1143	1143	1143	1346
Adjusted R^2	0.043	0.030	0.066	0.033	0.064

Panel B: Post-Match difference

	Emissions	Revenue	Employees	Assets	Emission Intensity
matched sample	-0.270***	-0.0374	0.694***	0.214	-0.232
	(0.104)	(0.171)	(0.186)	(0.168)	(0.170)
Observations	1080	1080	1080	1080	1080
Adjusted R^2	0.017	-0.001	0.043	0.003	0.004

Notes: This table presents coefficients capturing differences in outcome variables between treatment and control firms in 2017. Emission intensity refers to sectoral emission intensity data from the European Commission. Panel A uses the unmatched sample, while Panel B uses the matched sample based on Mahalanobis nearest-neighbour matching. All outcome variables are log-transformed. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

The Table C6 presents estimates from OLS regressions, estimated on a matched sample.

[18]Measured as the ratio of total verified emissions to revenue.

Standard errors are clustered in two ways, at the firm level and at the matching group level. Each estimate reflects the difference between regulated firm and unregulated firm outcomes relative to the year 2017. The results on emissions, revenue and assets remain robust, while the estimates for the specification on employment are not significant. We use five nearest neighbors to increase the effective sample size, and show below that the results remain robust to alternative matching specifications.

Table C6: The Effect on the Environmental and Economics Performance of Firms

	Verified Emissions	Revenue	Employees	Assets
Treatment 2018	-0.101***	0.005	-0.017	0.005
	(0.026)	(0.024)	(0.025)	(0.023)
Treatment 2021	-0.111***	-0.086**	-0.005	-0.081**
	(0.036)	(0.038)	(0.028)	(0.036)
Observations	3025	2863	2863	2863
Adjusted R^2	0.032	0.009	-0.000	0.010

Notes: This table presents estimates from OLS regressions, estimated on a matched sample. Standard errors are clustered in two ways, at the firm-level and at the matching group level. Each estimate reflects the difference between regulated firm and unregulated firm outcomes relative to the year 2017. All outcome variables are log-transformed. We present estimates for two time periods: when the reform is announced in 2018 and when the reform is implemented in 2021. Different matching specifications are presented in each column. Significance levels are indicated as * 0.10 ** 0.05 *** 0.01.

Table C7 shows that our main results for verified emissions are robust to using Euclidean distance, matching without replacement, and reducing the number of nearest neighbors. Table C8 further shows that the results remain robust when imposing alternative restrictions on distance, whereby matched observations are retained only if their pairwise distance lies below a given percentile of the distance distribution, corresponding to increasingly stringent closeness cutoffs.

Table C7: Alternative Matching Specifications

	Euclidean	No replacement	4NN	3NN	2NN	1NN
Treatment 2018	-0.104***	-0.107***	-0.098***	-0.103***	-0.108***	-0.106***
	(0.028)	(0.025)	(0.025)	(0.027)	(0.025)	(0.032)
Treatment 2021	-0.100***	-0.100***	-0.112***	-0.113***	-0.123***	-0.113**
	(0.037)	(0.034)	(0.036)	(0.038)	(0.036)	(0.045)
Observations	3025	3025	2420	1815	1210	605
Adjusted R^2	0.027	0.029	0.032	0.032	0.039	0.031

Notes: This table presents estimates from OLS regressions, estimated on a matched sample. Standard errors are clustered in two ways, at the firm-level and at the matching group level. Each estimate reflects the difference between regulated firm and unregulated firm outcomes relative to the year 2017. All outcome variables are log-transformed. We present estimates for two time periods: when the reform is announced in 2018 and when the reform is implemented in 2021. Different matching specifications are presented in each column. Significance levels are indicated as * 0.10 ** 0.05 *** 0.01.

Table C8: Alternative Distance Restrictions

	99th Percentile	95th Percentile	90th Percentile	75th Percentile
Treatment 2018	-0.103***	-0.099***	-0.104***	-0.100***
	(0.028)	(0.027)	(0.028)	(0.028)
Treatment 2021	-0.101***	-0.100***	-0.099**	-0.094**
	(0.038)	(0.038)	(0.039)	(0.039)
Observations	2995	2890	2746	2308
Adjusted R^2	0.027	0.026	0.026	0.024

Notes: This table presents estimates from OLS regressions, estimated on a matched sample. Standard errors are clustered in two ways, at the firm-level and at the matching group level. Each estimate reflects the difference between regulated firm and unregulated firm outcomes relative to the year 2017. All outcome variables are log-transformed. We present estimates for two time periods: when the reform is announced in 2018 and when the reform is implemented in 2021. Different matching specifications are presented in each column. Significance levels are indicated as * 0.10 ** 0.05 *** 0.01.

D Analysis on Trade

D.1 Data

To analyze trade patterns, we rely on the ComExt Intra- and Extra-European trade database, published by Eurostat. The data is available at the annual level and include information on the declarant country, partner country, trade value in euros, trade type (import or export) and the 4-digit CPA code for the sector. Using a common key, we translate the CPA sector codes to the 4-digit NACE classification. We apply the same classification of treated and control sectors as described in Table B1, consistent with the firm-level analysis.

In addition, we draw on tariff data from UNCTAD's TRAINS database, accessed through the World Integrated Trade Solution (WITS). These data are harmonized across countries at the 6-digit level of the Harmonized System and are available annually at the declarant–partner country level. We translate the 6-digit HS codes to the 4-digit NACE sector classification using a mapping from Eurostat. For tariffs, we rely on preferential rates, which we obtain through the bulk download option on the WITS website.

D.2 Empirical Strategy

Relying on the same identification assumption as in our firm-level analysis, we estimate the effect of losing free allocation on trade flows using a difference-in-differences design, estimating the specification:

$$\ln y_{ji,s,t} = \tau_{ijt} + \tau_{ijs} + \rho D_{st} + \alpha T_{ijst} + u_{ji,s,t}. \tag{18}$$

The term $\ln y_{ji,s,t}$ is the value of imports or exports in sector s between declarant country i and partner country j during the year t. The specification includes country-pair-sector fixed effects τ_{ijs}, which control for time-invariant sectoral characteristics that may differ across each country pair. We further include country-pair–year fixed effects τ_{ijt} to absorb common shocks affecting all sectors in a given bilateral relationship at time t. As an additional control, we account for bilateral tariffs T_{ijst} that may vary over time and across sectors. The treatment indicator D_{st} is defined analogously to the main analysis, and its coefficient measures the average treatment effect on the treated (ATT). However, given that the variation used for identification is on the sector-year level, any shocks λ_{st} that appear on this level cannot be controlled for. If such shocks are present, the error can be expressed as

$$u_{ji,s,t} = \lambda_{st} + \epsilon_{ji,s,t}$$

and the probability limit of the OLS estimator becomes:

$$\mathbb{E}[\hat{\rho}] \;=\; \rho \;+\; \frac{\text{Cov}(D_{st}, \lambda_{st})}{\text{Var}(D_{st})}.$$

To address this concern, we employ a triple-difference framework, following Ulmer (2022), to analyze trade patterns. We obtain within-sector-year variation by comparing, for a given sector and year, trade flows between EU ETS member countries ij with trade flows between an EU ETS country i and a non-EU ETS partner country j:

$$Y_{ijst} = \tau_{ijt} + \tau_{ijs} + \delta_{st} + \rho_{DDD}\big[D_{st} \times ExtraETS_j\big] + \alpha T_{ijs} + \varepsilon_{ijst} \tag{19}$$

The idea is that intra-EU ETS trade provides a natural control group, as both trading partners are equally subject to the reform and thus capture sector-specific shocks that are unrelated to treatment. The treatment group consists of trade flows between EU ETS declarant countries and non-EU ETS partners, where only one side of the trade is directly exposed to the reform. In this setting, the interaction term $D_{st} \times ExtraETS_j$ identifies the differential change in extra-EU trade of treated sectors relative to intra-EU trade of the same sectors, thereby isolating the effect of losing free allowances on international competitiveness. The within-sector-year variation allows us to include sector-time fixed effects δ_{st}, without losing the variation necessary for identification, but still controlling for a potential bias of the estimate that is introduced by λ_{st}.

D.3 Results

Table D9 reports the estimates from equations 18 and 19. Columns (1) and (2) show the difference-in-differences specification, while columns (3) and (4) present the triple-differences specification that exploits variation between intra-EU ETS and extra-EU trade flows.

In the simple DiD specification (columns 1 and 2), the estimated treatment effects are close to zero and statistically insignificant, indicating that the reform did not generate systematic changes in either exports or imports when comparing treated and control sectors over time.

By contrast, the triple-differences results (columns 3 and 4) suggest a marginally significant decline in exports for treated sectors after the reform. This effect is consistent with our firm-level evidence showing that the loss of free allocation reduced revenue. Imports, however, remain unaffected across all specifications. Taken together, these results show that the effects on trade are very limited. If anything, we observe only a marginal decline in exports, which may be in line with the reduction in revenues documented at the firm level.

Table D9: Baseline Estimation

Dependent Variables:	Exports	Imports	Exports	Imports
Model:	(1)	(2)	(3)	(4)
Variables				
Treatment Effect 2018	-0.0361	-0.0152	-0.0519	-0.0051
	(0.0364)	(0.0412)	(0.0332)	(0.0686)
Fixed-effects				
Sector-i-j	Yes	Yes	Yes	Yes
Time-i-j	Yes	Yes	Yes	Yes
Sector-Time			Yes	Yes
Fit statistics				
Observations	343,945	394,026	343,945	394,026
R^2	0.91781	0.90598	0.91862	0.90666
Within R^2	6.34×10^{-5}	7.27×10^{-6}	2.83×10^{-5}	1.75×10^{-7}

Notes: This table presents estimates from the difference-in-differences specification (columns 1 and 2) and from the triple-differences specifications (columns 3 and 4). All outcome variables are log-transformed. We present estimates for the year the policy reform was announced. Significance levels are indicated as * 0.10 ** 0.05 *** 0.01.

E Model Derivations

E.1 Aggregation

Prices

By starting from Equation 4 the firm-level price P_j can be expressed as:

$$P_j = \left(\int_{\Omega_j} p_j(\varphi)^{1-\sigma} d\varphi \right)^{\frac{1}{1-\sigma}} = \left[\int_0^\infty p_j(\varphi)^{1-\sigma} \underbrace{M_j}_{\text{Total mass}} \underbrace{\mu(\varphi)\, d\varphi}_{\text{Probability of landing near } \varphi} \right]^{\frac{1}{1-\sigma}}.$$

Using the pricing rule, we can get an expression for P_j:

$$\begin{aligned}
P_j^{1-\sigma} &= \int_0^\infty p_j(\varphi)^{1-\sigma}\, M_j\, \mu(\varphi)\, d\varphi \\
&= \int_0^\infty \left(\frac{\sigma}{\sigma-1} \frac{\Psi}{\varphi} \right)^{1-\sigma} M_j\, \mu(\varphi)\, d\varphi \\
&= M_j \left(\frac{\sigma}{\sigma-1} \Psi \right)^{1-\sigma} \underbrace{\int_0^\infty \varphi^{\sigma-1}\, \mu(\varphi)\, d\varphi}_{\equiv \tilde{\varphi}^{\sigma-1}} \\
&= M_j \underbrace{\left(\frac{\sigma}{\sigma-1} \frac{\Psi}{\tilde{\varphi}} \right)^{1-\sigma}}_{p_j(\tilde{\varphi})^{1-\sigma}}
\end{aligned}$$

where $\tilde{\varphi} \equiv \left[\int_0^\infty \varphi^{\sigma-1}\, \mu(\varphi)\, d\varphi \right]^{\frac{1}{\sigma-1}}$. Aggregating to the top nest gives:

$$\begin{aligned}
P^{1-\varepsilon} &= \sum_j \left(M_j^{\frac{1}{1-\sigma}} p_j(\tilde{\varphi}_j) \right)^{1-\varepsilon} \\
&= \sum_j \left(M_j^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma-1} \frac{\Psi}{\tilde{\varphi}_j} \right)^{1-\varepsilon} \\
&= \left(\frac{\sigma}{\sigma-1} \Psi \right)^{1-\varepsilon} \sum_j M_j^{\frac{1-\varepsilon}{1-\sigma}} \tilde{\varphi}_j^{\varepsilon-1} \\
\Rightarrow P &= \left(\frac{\sigma}{\sigma-1} \Psi \right) \left[\sum_j M_j^{\frac{1-\varepsilon}{1-\sigma}} \tilde{\varphi}_j^{\varepsilon-1} \right]^{\frac{1}{1-\varepsilon}}
\end{aligned}$$

We can then derive the firm-level aggregate price relative to the economy-wide aggregate price, which gives Equation 7:

$$\frac{P_j}{P} = \frac{\dfrac{\sigma}{\sigma-1}\Psi\, M_j^{-\frac{1}{\sigma-1}}\tilde{\varphi}_j^{-1}}{\dfrac{\sigma}{\sigma-1}\Psi\left(\sum_m M_m^{\frac{\varepsilon-1}{\sigma-1}}\tilde{\varphi}_m^{\varepsilon-1}\right)^{-\frac{1}{\varepsilon-1}}} = \frac{M_j^{-\frac{1}{\sigma-1}}\tilde{\varphi}_j^{-1}}{\left(\sum_m^N M_m^{\frac{\varepsilon-1}{\sigma-1}}\tilde{\varphi}_m^{\varepsilon-1}\right)^{-\frac{1}{\varepsilon-1}}}$$

Quantity, Revenue and Profits

From Equation 5, we know that:

$$q_j(\varphi) = q_j(\tilde{\varphi})\left(\frac{\varphi}{\tilde{\varphi}}\right)^{\sigma}$$

Combining this expression with the utility function gives:

$$\begin{aligned} Q_j &= \left(\int_{\Omega_j} q_j(\varphi)^{\frac{\sigma-1}{\sigma}}\, d\varphi\right)^{\frac{\sigma}{\sigma-1}} \\ &= \left(\int_0^{\infty} q_j(\varphi_j)^{\frac{\sigma-1}{\sigma}}\, M_j\mu(\varphi_j)d\varphi_j\right)^{\frac{\sigma}{\sigma-1}} \\ &= \left(\int_0^{\infty}\left(q_j(\tilde{\varphi})\left(\frac{\varphi}{\tilde{\varphi}}\right)^{\sigma}\right)^{\frac{\sigma-1}{\sigma}}\, M_j\mu(\varphi_j)d\varphi_j\right)^{\frac{\sigma}{\sigma-1}} \\ &= q_j(\tilde{\varphi})\tilde{\varphi}^{-\sigma}M_j^{\frac{\sigma}{\sigma-1}}\left(\int_0^{\infty}\varphi^{\sigma-1}\mu(\varphi_j)d\varphi_j\right)^{\frac{\sigma}{\sigma-1}} \\ &= q_j(\tilde{\varphi})\tilde{\varphi}^{-\sigma}M_j^{\frac{\sigma}{\sigma-1}}\tilde{\varphi}^{\sigma} = q_j(\tilde{\varphi})M_j^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

Similarly, we can calculate R_j:

$$
\begin{aligned}
R_j &= \int_0^\infty r_j(\varphi_j)\, M_j \mu(\varphi_j) d\varphi_j \\
&= \int_0^\infty r_j(\tilde{\varphi}) \left(\frac{\varphi_j}{\tilde{\varphi}}\right)^{\sigma-1} M_j \mu(\varphi_j) d\varphi_j \\
&= M_j r_j(\tilde{\varphi}) \tilde{\varphi}^{1-\sigma} \underbrace{\int_0^\infty \varphi_j^{\sigma-1} \mu(\varphi_j) d\varphi_j}_{\equiv \tilde{\varphi}^{\sigma-1}} \\
&= M_j r_j(\tilde{\varphi})
\end{aligned}
$$

Finally, firm-level profits Π_j can be found by:

$$
\begin{aligned}
\Pi_j &= \int_0^\infty \pi_j(\varphi)\, M_j\, \mu_j(\varphi)\, d\varphi \\
&= \int_0^\infty \left[\frac{1}{\sigma} r_j(\tilde{\varphi}_j) \left(\frac{\varphi}{\tilde{\varphi}_j}\right)^{\sigma-1} - F_j\right] M_j\, \mu_j(\varphi)\, d\varphi \\
&= \frac{M_j}{\sigma} r_j(\tilde{\varphi}_j) \tilde{\varphi}_j^{1-\sigma} \underbrace{\int_0^\infty \varphi^{\sigma-1} \mu_j(\varphi)\, d\varphi}_{\tilde{\varphi}_j^{\sigma-1}} - F_j M_j \underbrace{\int_0^\infty \mu_j(\varphi)\, d\varphi}_{1} \\
&= \frac{M_j}{\sigma} r_j(\tilde{\varphi}_j) - F_j M_j \\
&= M_j \underbrace{\left(\frac{r_j(\tilde{\varphi}_j)}{\sigma} - F_j\right)}_{\pi(\tilde{\varphi}_j)} \\
&= M_j \pi(\tilde{\varphi}_j)
\end{aligned}
$$

E.2 Policy Implementation

Fixed cost and the relative price of the treated firm

We start with the expression for relative prices in firm j:

$$
\frac{P_j}{P} = \frac{M_j^{-\frac{1}{\sigma-1}} \tilde{\varphi}_j^{-1}}{\left(\sum_m \left[M_m^{-\frac{1}{\sigma-1}} \tilde{\varphi}_m^{-1}\right]^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}}
$$

$$
\begin{aligned}
\frac{\partial}{\partial F_j}\ln\left(\frac{P_j}{P_{-j}}\right) =& -\frac{1}{\sigma-1}\frac{1}{M_j}\frac{\partial M_j}{\partial F_j}-\frac{1}{\tilde{\varphi}_j}\frac{\partial\tilde{\varphi}_j}{\partial F_j}\\
&-\frac{1}{1-\varepsilon}\frac{1}{\sum\limits_{m\neq j}\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]^{1-\varepsilon}}\frac{\partial}{\partial F_j}\left(\sum_{m\neq j}\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]^{1-\varepsilon}\right)
\end{aligned}
$$

Then take the inner derivatives:

$$
\frac{\partial}{\partial F_j}\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]^{1-\varepsilon}=(1-\varepsilon)\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]^{-\varepsilon}\frac{\partial}{\partial F_j}\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]
$$

where

$$
\frac{\partial}{\partial F_j}\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]=\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]\left[\frac{1}{\sigma-1}\frac{1}{M_m}\frac{\partial M_m}{\partial F_j}-\frac{1}{\tilde{\varphi}_m}\frac{\partial\tilde{\varphi}_m}{\partial F_j}\right]
$$

Bringing this back to the original derivative gives:

$$
\begin{aligned}
\frac{\partial}{\partial F_j}\ln\left(\frac{P_j}{P_{-j}}\right) =& -\frac{1}{\sigma-1}\frac{1}{M_j}\frac{\partial M_j}{\partial F_j}-\frac{1}{\tilde{\varphi}_j}\frac{\partial\tilde{\varphi}_j}{\partial F_j}\\
&-\frac{\sum\limits_{m\neq j}\left[M_m^{-\frac{1}{\sigma-1}}\tilde{\varphi}_m^{-1}\right]^{1-\varepsilon}\left[-\frac{1}{\sigma-1}\frac{1}{M_m}\frac{\partial M_m}{\partial F_j}-\frac{1}{\tilde{\varphi}_m}\frac{\partial\tilde{\varphi}_m}{\partial F_j}\right]}{\sum\limits_{k\neq j}\left[M_k^{-\frac{1}{\sigma-1}}\tilde{\varphi}_k^{-1}\right]^{1-\varepsilon}}\\
=& -\frac{1}{\sigma-1}\frac{1}{M_j}\frac{\partial M_j}{\partial F_j}-\frac{1}{\tilde{\varphi}_j}\frac{\partial\tilde{\varphi}_j}{\partial F_j}\\
&-\sum_{m\neq j}\frac{R_m}{R_{-j}}\left[-\frac{1}{\sigma-1}\frac{1}{M_m}\frac{\partial M_m}{\partial F_j}-\frac{1}{\tilde{\varphi}_m}\frac{\partial\tilde{\varphi}_m}{\partial F_j}\right]
\end{aligned}
$$

Sign of the different Impact Channels

In this section, we show the sign for the entry-flow, selection and composition channels. This requires to show the sign for:

$$
\frac{d\varphi_j^*}{dF_j}\quad,\quad\frac{\partial\tilde{\varphi}_j}{\partial\varphi_j^*}\quad\text{and}\quad\frac{\partial n_j}{\partial F_j}
$$

We start with using the ZPC and the free entry condition:

$$\bar{\pi}_j = F_j \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-1} - 1 \right]$$
$$\bar{\pi}_j = \frac{\delta f_{e,j}}{1 - G(\varphi_j^*)}$$

They can be equated which yields the following equation:

$$F_j \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-1} - 1 \right] = \frac{\delta f_{e,j}}{1 - G(\varphi_j^*)} \tag{20}$$

I'll use this expression to take the derivative of φ_j^* with respect to F_j. To do this, I'll apply the Implicit Function Theorem. So, as a brief detour, let's discuss the Implicit Function Theorem:

Left hand side:

$$\frac{\partial}{\partial F_j} \{F_j[\cdots]\} = \left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-1} - 1 + F_j \frac{\partial \varphi_j^*}{\partial F_j} \frac{\partial}{\partial \varphi_j^*} \left[\left(\frac{\tilde{\varphi}_j(\varphi_j^*)}{\varphi_j^*} \right)^{\sigma-1} - 1 \right]$$

We have two inner derivatives here:

$$\frac{\partial}{\partial \varphi_j^*} \left[\left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-1} - 1 \right] = (\sigma - 1) \left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-2} \underbrace{\frac{\partial}{\partial \varphi_j^*} \left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)}_{\frac{\tilde{\varphi}_j'(\varphi_j^*)\, \varphi_j^* - \tilde{\varphi}_j(\varphi_j^*)}{(\varphi_j^*)^2}}$$

Therefore the LHS becomes:

$$\frac{\partial}{\partial F_j} \{F_j[\cdots]\} = \left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-1} - 1 + F_j(\sigma - 1) \left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-2} \frac{\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j}{(\varphi_j^*)^2} \frac{\partial \varphi_j^*}{\partial F_j}$$

Right hand side:

$$\frac{\partial}{\partial F_j} \frac{\delta f_{e,j}}{1 - G(\varphi_j^*)} = \frac{\delta f_{e,j}\, g(\varphi_j^*)}{[1 - G(\varphi_j^*)]^2} \frac{d\varphi_j^*}{dF_j}.$$

Now we can combine both sides:

$$\left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-1} - 1 + F_j(\sigma - 1) \left(\frac{\tilde{\varphi}_j}{\varphi_j^*} \right)^{\sigma-2} \frac{\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j}{(\varphi_j^*)^2} \frac{d\varphi_j^*}{dF_j} = \frac{\delta f_{e,j}\, g(\varphi_j^*)}{[1 - G(\varphi_j^*)]^2} \frac{d\varphi_j^*}{dF_j}.$$

and solve for $\frac{d\varphi_j^*}{dF_j}$:

$$\frac{d\varphi_j^*}{dF_j} = \frac{\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-1} - 1}{\frac{\delta f_{e,j}\, g(\varphi_j^*)}{[1-G(\varphi_j^*)]^2} - F_j(\sigma-1)\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-2} \frac{\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j}{(\varphi_j^*)^2}}$$

Using 20 we can replace the numerator with $\frac{\delta f_{e,j}}{F_j[1-G(\varphi_j^*)]}$ and get the general form:

$$\frac{\partial\varphi_j^*}{\partial F_j} = \frac{\frac{\delta f_{e,j}}{F_j[1-G(\varphi_j^*)]}}{\frac{\delta f_{e,j} g(\varphi_j^*)}{[1-G(\varphi_j^*)]^2} - F_j(\sigma-1)\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-2} \frac{\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j}{(\varphi_j^*)^2}}$$

$$\frac{\partial\varphi_j^*}{\partial F_j} = \frac{\frac{\delta f_{e,j}}{F_j[1-G]}}{\frac{\delta f_{e,j} g}{[1-G]^2}} \frac{1}{1 - \frac{F_j[1-G]^2}{\delta f_{e,j} g}(\sigma-1)\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-2} \frac{\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j}{(\varphi_j^*)^2}}$$

Thus:

$$\frac{\partial\varphi_j^*}{\partial F_j} = \frac{1-G(\varphi_j^*)}{g(\varphi_j^*)} \frac{1}{F_j} \frac{1}{1 - \frac{F_j[1-G(\varphi_j^*)]^2}{\delta f_{e,j} g(\varphi_j^*)}(\sigma-1)\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-2} \frac{\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j}{(\varphi_j^*)^2}} \quad (21)$$

21 is the general condition. In the following we will assume a Pareto tail distribution, which simplifies 21 and allows as to recover the sign of both, $\frac{\partial\varphi_j^*}{\partial F_j}$ and $\frac{\partial\tilde{\varphi}_j}{\partial\varphi_j^*}$. The Pareto tail distribution has the following properties:

Table E10: Pareto Tail Distribution

Object	**Expression**	**Interpretation**
$G(\varphi)$	$1 - \left(\frac{\varphi_{\min}}{\varphi}\right)^{\theta}$	CDF
$g(\varphi)$	$\theta\frac{\varphi_{\min}^{\theta}}{\varphi^{\theta+1}}$	PDF

So lets have a look what happens to $\tilde{\varphi}$ with this assumption in a few steps. Remember the definition of it is this:

$$\tilde{\varphi}_j = \left[\frac{1}{1-G(\varphi_j^*)} \int_{\varphi_j^*}^{\infty} \varphi^{\sigma-1} g(\varphi)\, d\varphi\right]^{\frac{1}{\sigma-1}}.$$

Start with the integral:

$$\int_{\varphi_j^*}^{\infty} \varphi^{\sigma-1} g(\varphi)\, d\varphi = \theta\, \varphi_{\min}^{\theta} \int_{\varphi_j^*}^{\infty} \varphi^{\sigma-\theta-2}\, d\varphi = \frac{\theta}{\theta+1-\sigma}\, \varphi_{\min}^{\theta}\, (\varphi_j^*)^{\sigma-\theta-1}.$$

We also know that $1-G(\varphi_j^*) = \left(\frac{\varphi_{\min}}{\varphi_j^*}\right)^{\theta}$, so we use that combined with the previous equation

$$\frac{1}{1-G(\varphi_j^*)} \int_{\varphi_j^*}^{\infty} \varphi^{\sigma-1} g(\varphi)\, d\varphi = \frac{\theta}{\theta+1-\sigma}\, (\varphi_j^*)^{\sigma-1}.$$

$$\tilde{\varphi}_j = \left[\frac{1}{1-G(\varphi_j^*)} \int_{\varphi_j^*}^{\infty} \varphi^{\sigma-1} g(\varphi)\, d\varphi\right]^{\frac{1}{\sigma-1}} = \left(\frac{\theta}{\theta+1-\sigma}\right)^{\frac{1}{\sigma-1}} \varphi_j^*$$

So we can take the derivative of that wrt φ^*:

$$\frac{\partial \tilde{\varphi}_j}{\partial \varphi_j^*} = \frac{\partial}{\partial \varphi^*}\Big(\left(\frac{\theta}{\theta+1-\sigma}\right)^{\frac{1}{\sigma-1}} \varphi_j^*\Big) = \left(\frac{\theta}{\theta+1-\sigma}\right)^{\frac{1}{\sigma-1}}$$

$$\frac{\partial \tilde{\varphi}_j}{\partial \varphi_j^*} = \left(\frac{\theta}{\theta+1-\sigma}\right)^{\frac{1}{\sigma-1}} \tag{22}$$

With the Pareto tail distribution, $\frac{\partial \tilde{\varphi}_j}{\partial \varphi_j^*}$ becomes a constant. This property simplifies 21 significantly. Note first that:

$$\tilde{\varphi}_j' \varphi_j^* - \tilde{\varphi}_j = \left(\frac{\theta}{\theta+1-\sigma}\right)^{\frac{1}{\sigma-1}} \varphi_j^* - \left(\frac{\theta}{\theta+1-\sigma}\right)^{\frac{1}{\sigma-1}} \varphi_j^* = 0$$

Thus,

$$\begin{aligned}
\frac{\partial \varphi_j^*}{\partial F_j} &= \frac{1-G(\varphi_j^*)}{g(\varphi_j^*)}\frac{1}{F_j}\frac{1}{1-\frac{F_j[1-G(\varphi_j^*)]^2}{\delta f_{e,j} g(\varphi_j^*)}(\sigma-1)\left(\frac{\tilde{\varphi}_j}{\varphi_j^*}\right)^{\sigma-2}\underbrace{\frac{\tilde{\varphi}_j'\varphi_j^*-\tilde{\varphi}_j}{(\varphi_j^*)^2}}_{=0}} \\
&= \frac{1-G(\varphi_j^*)}{g(\varphi_j^*)}\frac{1}{F_j} \\
&= \frac{1}{F_j}\frac{1}{\frac{g(\varphi_j^*)}{1-G(\varphi_j^*)}} \\
&= \frac{1}{F_j}\frac{1}{\frac{\theta}{\varphi_j^*}}
\end{aligned}$$

$$\frac{\partial \varphi_j^*}{\partial F_j} = \frac{\varphi_j^*}{\theta F_j} > 0 \tag{23}$$

With 22 and 23, we can show that the selection channel, as well as the composition channel have the sign that we stated in the main text. Now we are left with entry-flow channel. The sign of this channel depends on the sign of $\frac{dn_j}{dF_j}$. Unfortunately, the sign of $\frac{dn_j}{dF_j}$ cannot be pinned down by the supply side alone (ZPC and FE).

To see that $\frac{\partial n_j}{\partial F_j} < 0$, we write profits in terms of entry attempts. Firms then choose the flow of attempts n_j optimally, such that marginal expected operating surplus are equal to the attempt cost. We start with per period profits of firm j before imposing the free entry condition:

$$\Pi_j = M_j \bar{\pi}_j - n_j f_{e,j}$$

Using $\bar{\pi}_j = \frac{\bar{r}_j}{\sigma} - F_j$, we get:

$$\Pi_j = M_j\left(\frac{\bar{r}_j}{\sigma} - F_j\right) - n_j f_{e,j} = \frac{1}{\sigma}\underbrace{(M_j \bar{r}_j)}_{R_j(M_j,\tilde{\varphi}_j)} - F_j M_j - n_j f_{e,j}$$

So we end up with:

$$\Pi_j(n_j, F_j) = \frac{1}{\sigma}R_j(M_j,\tilde{\varphi}_j) - F_j \underbrace{M_j}_{\frac{n_j}{\delta}[1-G(\varphi_j^*)]} - n_j f_{e,j}$$

Now taking the derivative wrt n_j gives:

$$\frac{\partial \Pi_j}{\partial n_j} = \left[\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} - F_j\right]\frac{1 - G(\varphi_j^*)}{\delta} - f_{e,j}$$

This we set equal to zero and define as:

$$\Phi(n_j, F_j) \equiv \left[\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} - F_j\right]\frac{1 - G(\varphi_j^*)}{\delta} - f_{e,j} = 0$$

Now we can apply the implicit function theorem to get:

$$0 = \frac{\partial \Phi}{\partial F_j} = \underbrace{\Phi_n}_{\partial\Phi/\partial n_j}\frac{dn_j}{dF_j} + \underbrace{\Phi_F}_{\partial\Phi/\partial F_j}$$

which we can solve for $\frac{dn_j}{dF_j}$:

$$\frac{\partial n_j}{\partial F_j} = -\frac{\Phi_F}{\Phi_n}$$

It becomes obvious that the sign depends on the sign of Φ_F and Φ_n. Both of those are concave and therefore negative. To see that more clearly, let's start with $\Phi_n < 0$. φ_j^* is fixed, since it is pinned down by ZCP and FE. So $\frac{\partial M_j}{\partial n_j} = \frac{1-G(\varphi_j^*)}{\delta}$. Taking all this togehter gives, as long as we assume diminishing returns to variety ($\frac{\partial^2 R_j}{\partial M_j^2}$):

$$\Phi_n = \frac{1}{\sigma}\frac{\partial^2 R_j}{\partial M_j^2}\left(\frac{\partial M_j}{\partial n_j}\right)\frac{1-G}{\delta} = \frac{1}{\sigma}\frac{\partial^2 R_j}{\partial M_j^2}\left(\frac{1-G}{\delta}\right)^2 < 0$$

To see that $\Phi_F < 0$, we differentiate Φ with respect to F_j and get:

$$\Phi_F = \underbrace{\left[\frac{1}{\sigma}\frac{\partial^2 R_j}{\partial M_j \partial F_j} - 1\right]\frac{1-G}{\delta}}_{\text{direct cost + change in MR}} + \underbrace{\left[\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} - F_j\right]\frac{\partial}{\partial F_j}\left(\frac{1-G}{\delta}\right)}_{\text{cutoff/survival effect}}$$

The survival effect is negative, as already discussed above, since: $\frac{\partial}{\partial F_j}\left(\frac{1-G(\varphi_j^*)}{\delta}\right) = -\frac{g(\varphi_j^*)}{\delta}\frac{d\varphi_j^*}{dF_j} < 0$, or using pareto tails $-\frac{1}{F_j}\frac{1-G}{\delta}$. At the optimum $\left[\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} - F_j\right]\frac{1-G}{\delta} = f_{e,j} \quad \Rightarrow \quad \left[\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} - F_j\right] = \frac{f_{e,j}\,\delta}{1-G} > 0$.

Finally note for the first term, that F_j affects R_j only via $\tilde{\varphi}_j$. This whole term summarizes the fact that fixed cost have a direct cost on each surviving product line (-1), which gets partly offset by the fact that the remaining pool of product lines are on average more productive.

To see under which conditions the direct effect dominates, start with:

$$\frac{1}{\sigma}\frac{\partial^2 R_j}{\partial M_j\,\partial F_j} = \frac{\varepsilon-1}{\theta F_j}\left(\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j}\right)$$

We can find an expression for $\left(\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j}\right)$ by using the FOC: $\left[\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} - F_j\right]\frac{1-G(\varphi_j^*)}{\delta} = f_{e,j} \quad \Rightarrow$ $\frac{1}{\sigma}\frac{\partial R_j}{\partial M_j} = F_j + \frac{f_{e,j}\,\delta}{[1-G(\varphi_j^*)]}$. This property can be used for the whole expression to get:

$$\begin{aligned}\Phi_F &= \left(\frac{\varepsilon-1}{\theta} - 1\right)\frac{1-G(\varphi_j^*)}{\delta} + \frac{\varepsilon-1}{\theta}\frac{f_{e,j}}{F_j} - \frac{f_{e,j}}{F_j}\\ &= \left(\frac{\varepsilon-1}{\theta} - 1\right)\left[\frac{1-G(\varphi_j^*)}{\delta} + \frac{f_{e,j}}{F_j}\right]\end{aligned}$$

Under the condition that $\theta > \varepsilon - 1$, we can conclude that $\Phi_F < 0$.

Therefore $-\frac{\Phi_F}{\Phi_n} < 0$ and $\frac{dn_j}{dF_j} < 0$.

Dominance of Entry-flow and Selection Channel

Now that we are sure about the sign of each of the channels that affect $\frac{P_j}{P}$, we show under which conditions the selection and entry-flow channel dominate the composition channel. To see which of the effects are larger, we start from the stationarity condition and take the derivative with respect to F_j:

$$\frac{\partial \ln M_j}{\partial F_j} = \frac{\partial \ln n_j}{\partial F_j} + \frac{\partial}{\partial F_j}\ln[1-G(\varphi_j^*)]$$

Using the earlier result $\partial\varphi_j^*/\partial F_j = \varphi_j^*/(\theta F_j)$, and $\frac{\partial}{\partial F_j}\ln[1-G(\varphi_j^*)] = -\frac{g}{1-G}\frac{d\varphi_j^*}{dF_j} = -\frac{1}{F_j}$, from the Pareto tail distribution, we can write:

$$\frac{1}{M_j}\frac{\partial M_j}{\partial F_j} = \frac{1}{n_j}\frac{\partial n_j}{\partial F_j} - \frac{1}{F_j}$$

We also showed above that

$$\frac{\partial \ln \tilde{\varphi}_j}{\partial F_j} = \frac{1}{\varphi_j^*}\frac{\partial \varphi_j^*}{\partial F_j} = \frac{1}{\theta F_j}$$

We can plug those two expressions in the bracket of 11:

$$\frac{\partial}{\partial F_j}\ln\left(\frac{P_j}{P}\right) = \left[-\frac{1}{\sigma-1}\left(\frac{1}{n_j}\frac{\partial n_j}{\partial F_j} - \frac{1}{F_j}\right) - \frac{1}{\theta F_j}\right] + \text{(GE spillover)}$$

$$= \left[\underbrace{\frac{1}{\sigma-1}\left(-\frac{1}{n_j}\frac{\partial n_j}{\partial F_j} + \frac{1}{F_j}\right)}_{\text{Selection and Entry}} + \underbrace{\left(-\frac{1}{\theta F_j}\right)}_{\text{composition (via } \tilde{\varphi}_j)}\right] + \text{(GE spillover)}$$

The selection and entry effect dominates iff:

$$\frac{1}{\sigma-1}\left(-\frac{1}{n_j}\frac{\partial n_j}{\partial F_j} + \frac{1}{F_j}\right) > \frac{1}{\theta F_j}.$$

$$-\frac{1}{n_j}\frac{\partial n_j}{\partial F_j} > \frac{(\sigma-1)-\theta}{\theta}\frac{1}{F_j}$$

As shown above, $\frac{\partial n_j}{\partial F_j} < 0$. That implies that the LHS > 0. So this inequality holds certainly iff $\theta > \sigma - 1$.

General Equilibrium Spillover

We begin from

$$\frac{\partial}{\partial F_j}\ln\left(\frac{P_j}{P}\right) = \left(1 - \frac{R_j}{R}\right)\left[-\frac{1}{\sigma-1}\frac{1}{M_j}\frac{\partial M_j}{\partial F_j} - \frac{1}{\tilde{\varphi}_j}\frac{\partial \tilde{\varphi}_j}{\partial F_j}\right] - \underbrace{\sum_{m\neq j}\frac{R_m}{R}\left[-\frac{1}{\sigma-1}\frac{1}{M_m}\frac{\partial M_m}{\partial F_j} - \frac{1}{\tilde{\varphi}_m}\frac{\partial \tilde{\varphi}_m}{\partial F_j}\right]}_{\text{GE effects}}$$

The second sum represents the *general-equilibrium effects*. Inside it, two channels appear:

$$\frac{\partial M_m}{\partial F_j}, \qquad \frac{\partial \tilde{\varphi}_m}{\partial F_j}$$

In this section, we show that $\frac{\partial \tilde{\varphi}_m}{\partial F_j} = 0$ and $\frac{\partial M_m}{\partial F_j} > 0$. Therefore, the GE effects amplify the increase of the relative price $\frac{P_j}{P}$. Consider first

$$\frac{\partial \tilde{\varphi}_m}{\partial F_j} = \frac{\partial \tilde{\varphi}_m}{\partial \varphi_m^*}\frac{\partial \varphi_m^*}{\partial F_j}$$

The cutoff φ_m^* is pinned down by the zero-profit and free-entry conditions:

$$F_m\left[\left(\frac{\tilde{\varphi}_m}{\varphi_m^*}\right)^{\sigma-1} - 1\right] = \frac{\delta f_{e,m}}{1 - G(\varphi_m^*)}$$

Importantly, this equation contains *only* firm-m objects and parameters. It does not depend on F_j for $j \neq m$ and does not include variables that would transmit GE effects into φ_m^*. Since $\tilde{\varphi}_m = \tilde{\varphi}_m(\varphi_m^*)$ and φ_m^* is independent of F_j for $m \neq j$, we obtain

$$\frac{\partial \tilde{\varphi}_m}{\partial F_j} = 0, \qquad m \neq j$$

Thus all GE effects for $m \neq j$ operate through M_m only.

For M_m we have

$$\frac{\partial M_m}{\partial F_j} = \frac{\partial M_m}{\partial R_m} \frac{\partial R_m}{\partial F_j}$$

We focus on $\frac{\partial M_m}{\partial R_m}$ first. We already know how M_m depends on its own revenue R_m. Using the decomposition

$$\Pi_m = \underbrace{\frac{R_m}{\sigma} - F_m M_m}_{\text{Incumbent Profit}} = \underbrace{n_m f_{e,m}}_{\text{Entrant Cost}}$$

together with the stationarity condition:

$$M_m = \frac{n_m}{\delta}\left[1 - G(\varphi_m^*)\right]$$
$$n_m = \frac{\delta\, M_m}{1 - G(\varphi_m^*)}$$

We can plug this back to get:

$$\frac{R_m}{\sigma} - F_m M_m = n_m f_{e,m} = \frac{\delta\, M_m}{1 - G(\varphi_m^*)}\, f_{e,m}$$

$$\frac{R_m}{\sigma} = \left[F_m + \frac{\delta\, f_{e,m}}{1 - G(\varphi_m^*)}\right] M_m \implies M_m = \frac{1}{\sigma\left(F_m + \frac{\delta\, f_{e,m}}{1 - G(\varphi_m^*)}\right)} R_m$$

Taking the derivative with respect to R_m shows that the mass of product lines M_m increases by a constant when the firm-level revenue R_m increases. This constant depends only on m's own primitives, but not on F_j. The intuition is that more revenue in m means there is room to cover the per-line fixed cost for more lines. So M_m rises one for one with R_m:

$$\frac{dM_m}{dR_m} = \frac{1}{\sigma\left(F_m + \frac{\delta\, f_{e,m}}{1 - G(\varphi_m^*)}\right)} \;>\; 0$$

So we are left with the effect of F_j on φ_m^*, $\frac{\partial R_m}{\partial F_j}$. Revenues satisfy the CES demand system:

$$R_i = R\left(\frac{P_i}{P}\right)^{1-\varepsilon}, \qquad P = \left(\sum_{m=1}^{N} P_m^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

Differentiate $\ln R_m$ w.r.t. F_j for $m \neq j$:

$$\frac{\partial \ln R_m}{\partial F_j} = \underbrace{\frac{\partial \ln R}{\partial F_j}}_{=0} + (1-\varepsilon)\left(\underbrace{\frac{\partial \ln P_m}{\partial F_j}}_{=0} - \frac{\partial \ln P}{\partial F_j}\right)$$

Two objects equal zero here. First, $\frac{\partial \ln P_m}{\partial F_j}$ equals zero, since P_m only depends on M_m and $\tilde{\varphi}_m$. Also $\frac{\partial \ln R}{\partial F_j} = 0$. Since the labor supply is fixed and the wage is taken as a numeraire, wL remains unaffected by any change in F_j. Further, profits and government rebate exactly offset each other. To see that more clearly, take the derivative of the household budget constraint with respect to F_j:

$$\frac{\partial R}{\partial F_j} = \underbrace{\frac{\partial (wL)}{\partial F_j}}_{=0} + \underbrace{\left(\frac{\partial \Pi}{\partial F_j} - \frac{\partial T}{\partial F_j}\right)}_{=0}$$

This implies that $\frac{\partial \ln R_m}{\partial F_j}$ is determined by $\frac{\partial \ln P}{\partial F_j}$, which we can calculate:

$$P = \left(\sum_k P_k^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \quad \Longrightarrow \quad \ln P = \frac{1}{1-\varepsilon}\ln\left(\sum_k P_k^{1-\varepsilon}\right)$$

Then differentiate with respect to F_j:

$$\begin{aligned}\frac{\partial \ln P}{\partial F_j} &= \frac{1}{1-\varepsilon}\frac{1}{\sum_k P_k^{1-\varepsilon}}\frac{\partial}{\partial F_j}\Big(\sum_k P_k^{1-\varepsilon}\Big) \\ &= \frac{1}{1-\varepsilon}\frac{1}{\sum_k P_k^{1-\varepsilon}}\sum_k (1-\varepsilon)P_k^{-\varepsilon}\frac{\partial P_k}{\partial F_j} \\ &= \frac{\sum_k P_k^{1-\varepsilon}\,\frac{\partial \ln P_k}{\partial F_j}}{\sum_k P_k^{1-\varepsilon}}.\end{aligned}$$

Since only $k = j$ depends directly on F_j:

$$\sum_k P_k^{1-\varepsilon}\frac{\partial \ln P_k}{\partial F_j} = P_j^{1-\varepsilon}\frac{\partial \ln P_j}{\partial F_j} + \sum_{k\neq j} P_k^{1-\varepsilon}\underbrace{\frac{\partial \ln P_k}{\partial F_j}}_{=0}$$

Then we can plug this back and use the identity $P^{1-\varepsilon} = \sum_k P_k^{1-\varepsilon}$ to get:

$$\begin{aligned}\frac{\partial \ln P}{\partial F_j} &= \frac{P_j^{1-\varepsilon}}{\sum_k P_k^{1-\varepsilon}}\frac{\partial \ln P_j}{\partial F_j}, \\ &= \left(\frac{P_j}{P}\right)^{1-\varepsilon}\frac{\partial \ln P_j}{\partial F_j}\end{aligned}$$

Finally we get:

$$\frac{\partial \ln R_m}{\partial F_j} = (\varepsilon - 1)\left(\frac{P_j}{P}\right)^{1-\varepsilon}\frac{\partial \ln P_j}{\partial F_j} > 0$$

Coming back to our initial question about $\frac{\partial M_m}{\partial F_j}$. This allows us to conclude that:

$$\frac{\partial M_m}{\partial F_j} = \underbrace{\frac{\partial M_m}{\partial R_m}}_{+}\underbrace{\frac{\partial R_m}{\partial F_j}}_{+} > 0$$

E.3 Policy Announcement

Technology Adaptation Cutoff

We start with the expression for revenue of a given product line:

$$r_j(\varphi) = R_j \left(\frac{p_j(\varphi)}{P_j} \right)^{1-\sigma}$$

If one variant φ_0 would adopt the technology, it now has the new price: $p'_j(\varphi_0) = m\, p_j(\varphi_0)$. Given that product lines are atomistic, the set $\{\varphi_0\}$ has measure zero. Thus, the integrals above would not change ($P'_j = P_j$). Therefore:

$$\frac{r'_j(\varphi_0)}{r_j(\varphi_0)} = \left(\frac{p'_j(\varphi_0)/P'_j}{p_j(\varphi_0)/P_j} \right)^{1-\sigma} = \left(\frac{m\, p_j(\varphi_0)/P_j}{p_j(\varphi_0)/P_j} \right)^{1-\sigma} = m^{1-\sigma}$$

and

$$r_h(\varphi) = m^{1-\sigma} r_\ell(\varphi) \tag{24}$$

This allows us to calculate the gain for a product line from adoption. We know that the variable costs for $s \in \{\ell, h\}$, can be expressed as: $vc_s(\varphi) = \frac{\sigma-1}{\sigma} p_s(\varphi) q_s(\varphi) = \frac{\sigma-1}{\sigma} r_s(\varphi)$. Then,

$$\begin{aligned}
\pi_j(p) &= p_j\, q_j(\varphi) - c_u(\varphi) q_j(\varphi) - F_j \\
&= r_s(\varphi) - vc_s(\varphi) - F_j \\
&= r_s(\varphi) \left(1 - \frac{\sigma - 1}{\sigma} \right) - F_j \\
&= \frac{1}{\sigma} r_s(\varphi) - F_j
\end{aligned}$$

Therefore,

$$\pi_s(\varphi) = \frac{1}{\sigma} r_s(\varphi) - F_j \qquad s \in \{\ell, h\} \tag{25}$$

Using this definition of profits, we can derive the gain from adoption:

$$\begin{aligned}
\Delta\pi(\varphi) \equiv \pi_h(\varphi) - \pi_\ell(\varphi) &= \left[\frac{1}{\sigma} r_h(\varphi) - F_j \right] - \left[\frac{1}{\sigma} r_\ell(\varphi) - F_j \right] \\
&= \frac{1}{\sigma} [r_h(\varphi) - r_\ell(\varphi)]
\end{aligned}$$

Now, we can use 24 to express all in terms of $r_\ell(\varphi)$:

$$\begin{aligned}\Delta\pi(\varphi) &= \frac{1}{\sigma}[m^{1-\sigma}r_\ell(\varphi) - r_\ell(\varphi)] \\ &= \frac{1}{\sigma}(m^{1-\sigma} - 1)r_\ell(\varphi)\end{aligned}$$

So,

$$\Delta\pi(\varphi) = \frac{1}{\sigma}(m^{1-\sigma} - 1)r_\ell(\varphi)$$

is the additional profit that a product line receives from adapting the technology and equation 14 in the main text. We can put this in terms of present value of the firm:

$$\Delta v(\varphi) = \frac{\Delta\pi(\varphi)}{\delta}$$

To decide to adapt or not, this has to be related to the cost of adaptation K. The product line will adopt the new technology iff the gain in net present value will exceed the sunk cost K:

$$\Delta v(\varphi) \geq K \iff \frac{\Delta\pi(\varphi)}{\delta} \geq K \iff \Delta\pi(\varphi) \geq \delta K$$

Now, we can use equation 14:

$$\begin{aligned}\frac{1}{\sigma}(m^{1-\sigma} - 1)r_\ell(\varphi) &\geq \delta K \\ r_\ell(\varphi) &\geq \frac{\sigma\delta K}{m^{1-\sigma} - 1}\end{aligned}$$

Now using the ZPC and the revenue ladder, we get:

$$r_\ell(\varphi) = r(\varphi_j^*)\left(\frac{\varphi}{\varphi_j^*}\right)^{\sigma-1}, \qquad r(\varphi_j^*) = \sigma F_j$$

Combining those two we get:

$$\begin{aligned}
r(\varphi_j^*)\left(\frac{\varphi}{\varphi_j^*}\right)^{\sigma-1} &\geq \frac{\sigma\,\delta K}{m^{1-\sigma}-1} \\
\left(\frac{\varphi}{\varphi_j^*}\right)^{\sigma-1} &\geq \frac{\sigma\delta K}{r(\varphi_j^*)[m^{1-\sigma}-1]} \\
\frac{\varphi}{\varphi_j^*} &\geq \left[\frac{\sigma\delta K}{r(\varphi_j^*)[m^{1-\sigma}-1]}\right]^{1/(\sigma-1)} \\
\varphi &\geq \underbrace{\varphi_j^*\left[\frac{\sigma\delta K}{r(\varphi_j^*)[m^{1-\sigma}-1]}\right]^{1/(\sigma-1)}}_{\varphi_A}
\end{aligned}$$

This gives us the firm-level adoption cutoff:

$$\varphi_j^A = \varphi_j^*\left[\frac{\sigma\delta K}{r(\varphi_j^*)(m^{1-\sigma}-1)}\right]^{1/(\sigma-1)}$$

which is equation 15. Using the ZPC condition, this equation can be rewritten as:

$$\varphi_j^A = \varphi_j^*\left[\frac{\delta K}{F_j(m^{1-\sigma}-1)}\right]^{1/(\sigma-1)}$$

Note that the threshold is independent of changes in F_j. To see that clearly, we start at the revenue ladder. Evaluated at φ_j^*:

$$\partial \ln r(\varphi_j^*) = (\sigma-1)\,\partial \ln \varphi_j^*$$

Using the ZCP, we get:

$$\partial \ln r(\varphi_j^*) = \partial \ln(\sigma F_j) = \partial \ln F_j$$

Combining those two yields:

$$\frac{\partial \ln \varphi_j^*}{\partial \ln F_j} = \frac{1}{\sigma-1}$$

Taking logs of the expression for the productivity cutoff gives:

$$\ln \varphi_j^A = \ln \varphi_j^* + \frac{1}{\sigma-1}\big[\ln \delta K - \ln F_j - \ln(m^{1-\sigma}-1)\big]$$

Then we can take derivatives and conclude that F_j does not affect the cutoff directly:

$$\frac{\partial \ln \varphi_j^A}{\partial \ln F_j} = \underbrace{\frac{1}{\sigma-1}}_{\text{via } \varphi_j^*} - \underbrace{\frac{1}{\sigma-1}}_{\text{explicit } -\ln F_j \text{ in the bracket}} = 0$$

Anticipation

The increase in value of a given product line due to the adoption of the high-efficiency technology can be calculated using equation 25 and depends on the increase in revenue of the remaining product lines. During $t = 0$, profits remain unchanged at π_0. At $t = 1$, profits change and then stay at the new level at π_1 for upcoming all periods:

$$\begin{aligned}
\Delta v_0(\varphi) &= \Delta\pi_0(\varphi) + (1-\delta)\Delta\pi_1(\varphi) + (1-\delta)^2\Delta\pi_1(\varphi) + \dots \\
&= \Delta\pi_0(\varphi) + \frac{1-\delta}{\delta}\Delta\pi_1(\varphi). \\
&= \frac{1}{\sigma}(m^{1-\sigma}-1)\left[r_\ell^0(\varphi) + \frac{1-\delta}{\delta} r_\ell^1(\varphi)\right]
\end{aligned}$$

We know that product lines adapt at $t = 0$, iff $\Delta v_0(\varphi) \geq K$:

$$\begin{aligned}
\frac{1}{\sigma}(m^{1-\sigma}-1)\left[r_\ell^0(\varphi) + \frac{1-\delta}{\delta} r_\ell^1(\varphi)\right] &\geq K \\
r_\ell^0(\varphi) + \frac{1-\delta}{\delta} r_\ell^1(\varphi) &\geq \frac{\sigma K}{m^{1-\sigma}-1}
\end{aligned}$$

Defining $\Phi_j \equiv \frac{r_\ell^1(\varphi)}{r_\ell^0(\varphi)}$, we can rewrite the expression:

$$\begin{aligned}
r_\ell^0 + \frac{1-\delta}{\delta}\Phi_j\, r_\ell^0 &\geq \frac{\sigma K}{m^{1-\sigma}-1} \\
r_\ell^0\left(1 + \frac{1-\delta}{\delta}\Phi_j\right) &\geq \frac{\sigma K}{m^{1-\sigma}-1} \\
r_\ell^0(\varphi) &\geq \frac{\sigma K}{m^{1-\sigma}-1}\frac{1}{1+\frac{1-\delta}{\delta}\Phi_j}
\end{aligned}$$

Note that if $\Phi_j = 1$, so the revenue today and tomorrow are similar, we arrive at the same expression as before: $r_\ell^0 \geq \frac{\sigma K}{m^{1-\sigma}-1}\frac{1}{1+\frac{1-\delta}{\delta}} = \frac{\sigma K}{m^{1-\sigma}-1}\delta$. Again, we can get today's adoption cutoff:

$$\left(\frac{\varphi_A}{\varphi_j^{*0}}\right)^{\sigma-1} = \frac{K}{F_j^0(m^{1-\sigma}-1)}\frac{1}{1+\frac{1-\delta}{\delta}\Phi_j}$$

$$\varphi_A^0 = \varphi_j^{*0} \left[\frac{K}{F_j^0 (m^{1-\sigma} - 1)} \frac{1}{1 + \frac{1-\delta}{\delta} \Phi_j} \right]^{\frac{1}{\sigma-1}}$$

which is equation 16. Taking the derivative with respect to the announcement parameter Φ_j shows that an increase in revenue next period decreases the adoption productivity cutoff:

$$\frac{\partial \varphi_A^0}{\partial \Phi_j} = -\varphi_A^0 \frac{1}{\sigma - 1} \frac{(1-\delta)/\delta}{1 + \frac{1-\delta}{\delta} \Phi_j} < 0$$

What determines Φ_j? To see how firm j is affected by the announcement effect relative to all other firms $m \neq j$, we look closer at the relative revenue change of a product line due to the announcement. Starting from the revenue ladder:

$$\frac{r_\ell^1(\varphi)}{r_\ell^0(\varphi)} = \frac{R_j^1}{R_j^0} \left(\frac{p(\varphi)/P_j^1}{p(\varphi)/P_j^0} \right)^{1-\sigma} = \frac{R_j^1}{R_j^0} \left(\frac{P_j^0}{P_j^1} \right)^{1-\sigma}$$

which gives us:

$$\frac{r_\ell^1(\varphi)}{r_\ell^0(\varphi)} = \frac{R_j^1}{R_j^0} \left(\frac{P_j^1}{P_j^0} \right)^{\sigma-1} \tag{26}$$

We can express the firm revenue via the top nest using:

$$R_j^t = R^t \left(\frac{P_j^t}{P^t} \right)^{1-\varepsilon}$$

Thus,

$$\frac{R_j^1}{R_j^0} = \frac{R^1}{R^0} \left(\frac{P_j^1/P^1}{P_j^0/P^0} \right)^{1-\varepsilon} = \frac{R^1}{R^0} \left(\frac{P_j^1}{P_j^0} \right)^{1-\varepsilon} \left(\frac{P^0}{P^1} \right)^{1-\varepsilon}$$

This we plug into 26 to get:

$$\frac{r_\ell^1(\varphi)}{r_\ell^0(\varphi)} = \frac{R^1}{R^0} \left(\frac{P_j^1}{P_j^0} \right)^{(1-\varepsilon)+(\sigma-1)} \left(\frac{P^0}{P^1} \right)^{1-\varepsilon} = \frac{R^1}{R^0} \left(\frac{P_j^1}{P_j^0} \right)^{\sigma-\varepsilon} \left(\frac{P^1}{P^0} \right)^{\varepsilon-1}$$

So what we are left with is:

$$\frac{r_\ell^1(\varphi)}{r_\ell^0(\varphi)} = \underbrace{\frac{R^1}{R^0}}_{\text{aggregate expenditure}} \underbrace{\left(\frac{P_j^1}{P_j^0}\right)^{\sigma-\varepsilon}}_{\text{within-firm reallocation}} \underbrace{\left(\frac{P^1}{P^0}\right)^{\varepsilon-1}}_{\text{economy-wide price index}}$$

We can see that we have three components here. The aggregate expenditure captures the fact that the revenue of a product line increases when aggregate expenditure rises, for example due to higher income of households. In this case every product line in the economy sees an increase in their revenue of it's share in the economy. A change in F_j just reshuffles incomes between firms and the government. Less free allowances decrease firm profits, which is offset by lower taxes for households.

The economy-wide price effect describes the effect of changes in the economy-wide price level on the revenue of product lines of firm j. If prices of firm j rise in the next periode, the economy-wide price level P increases since P_j is part of P. On top of that, general equilibrium spillovers, as discussed in the last section, could decrease the P. However, for any of those effects to be quantitatively relevant, j has to be quite large compared to the rest of the economy, which doesn't reflect the empirical facts.

Finally, the within-firm reallocation is based on channels that define the announcement effect. First, the within-firm demand increases the demand for the variants remaining in the market. As discussed in the last chapter, the reform will increase the price level of firm j at $t = 1$, since higher fixed cost decreases the mass of product lines M_j, which makes it harder to reach a given utility due to love-of-variety preferences. The pricing rule of a product line, however, is independent of fixed costs. Therefore, a given product line becomes cheaper relative to the firm level price index P_j and has, therefore, a higher revenue. That positive effect on a line's revenue has strength $\sigma - 1$.

Second, given the higher firm-level price index P_j, firm j will lose some revenue to other firms $m \neq j$. That is given by the $1 - \varepsilon$. Therefore for each product line we see a change in revenue based on the change in P_j form $t = 0$ to $t = 1$ based on $\sigma - \varepsilon$.

We are especially interested in the effect of the announcement on the productivity cutoff for adoption in the treated firm j, relative to all other firms $m \neq j$. Therefore, we first look at the ratio:

$$\frac{\Phi_j}{\Phi_m} = \frac{\frac{R^1}{R^0}\left(\frac{P_j^1}{P_j^0}\right)^{\sigma-\varepsilon}\left(\frac{P^1}{P^0}\right)^{\varepsilon-1}}{\frac{R^1}{R^0}\left(\frac{P_m^1}{P_m^0}\right)^{\sigma-\varepsilon}\left(\frac{P^1}{P^0}\right)^{\varepsilon-1}}$$

$$= \underbrace{\frac{R^1/R^0}{R^1/R^0}}_{=1} \times \frac{\left(\frac{P_j^1}{P_j^0}\right)^{\sigma-\varepsilon}}{\left(\frac{P_m^1}{P_m^0}\right)^{\sigma-\varepsilon}} \times \underbrace{\frac{\left(\frac{P^1}{P^0}\right)^{\varepsilon-1}}{\left(\frac{P^1}{P^0}\right)^{\varepsilon-1}}}_{=1}$$

Then we get:

$$\frac{\Phi_j}{\Phi_m} = \left(\frac{P_j^1/P_j^0}{P_m^1/P_m^0}\right)^{\sigma-\varepsilon} \tag{27}$$

From our previous analysis, we know that with the implementation of the reform, $\frac{P_j^1}{P_j^0} > 1$. Moreover, the GE spillovers suggest that $\frac{P_m^1}{P_m^0} < 1$. This effect is most likely much smaller and only amplifies the main effect on the price index of the treated firm. Therefore, given that $\sigma > \varepsilon$, we can conclude that:

$$\frac{\partial}{\partial F_j^1} \ln\left(\frac{\Phi_j}{\Phi_m}\right) = (\sigma-\varepsilon)\left(\frac{\partial \ln P_j^1}{\partial F_j^1} - \frac{\partial \ln P_m^1}{\partial F_j^1}\right)$$

This has implications for the relative change in the productivity cutoff:

$$\frac{\varphi_{A,j}^0}{\varphi_{A,m}^0} = \left(\frac{1+\frac{1-\delta}{\delta}\,\Phi_m}{1+\frac{1-\delta}{\delta}\,\Phi_j}\right)^{\frac{1}{\sigma-1}}$$

Taking logs and differentiate gives:

$$\ln\left(\frac{\varphi_{A,j}^0}{\varphi_{A,m}^0}\right) = \frac{1}{\sigma-1}\Big[\ln\big(\delta+(1-\delta)\,\Phi_m\big) - \ln\big(\delta+(1-\delta)\,\Phi_j\big)\Big]$$

$$\frac{\partial}{\partial F_j^1}\ln\left(\frac{\varphi_{A,j}^0}{\varphi_{A,m}^0}\right) = \frac{1}{\sigma-1}\left[\frac{(1-\delta)\,\frac{\partial \Phi_m}{\partial F_j^1}}{\delta+(1-\delta)\,\Phi_m} - \frac{(1-\delta)\,\frac{\partial \Phi_j}{\partial F_j^1}}{\delta+(1-\delta)\,\Phi_j}\right]$$

Note that prior to the announcement, $\Phi_j = \Phi_m = 1$. So we evaluate the derivative using this fact:

$$\begin{aligned}
\frac{\partial}{\partial F_j^1}\ln\left(\frac{\varphi^0_{A,j}}{\varphi^0_{A,m}}\right)\Bigg|_{\Phi_j=\Phi_m=1} &= \frac{1-\delta}{\sigma-1}\left[\frac{\partial\Phi_m}{\partial F_j^1}-\frac{\partial\Phi_j}{\partial F_j^1}\right] \\
\frac{\partial}{\partial F_j^1}\ln\left(\frac{\Phi_j}{\Phi_m}\right)\Bigg|_{\Phi_j=\Phi_m=1} &= \left(\frac{1}{\Phi_j}\frac{\partial\Phi_j}{\partial F_j^1}-\frac{1}{\Phi_m}\frac{\partial\Phi_m}{\partial F_j^1}\right)\Bigg|_{\Phi_j=\Phi_m=1} \\
&= \frac{\partial\Phi_j}{\partial F_j^1}-\frac{\partial\Phi_m}{\partial F_j^1} \\
\frac{\partial}{\partial F_j^1}\ln\left(\frac{\varphi^0_{A,j}}{\varphi^0_{A,m}}\right)\Bigg|_{\Phi=1} &= -\frac{1-\delta}{\sigma-1}\frac{\partial}{\partial F_j^1}\ln\left(\frac{\Phi_j}{\Phi_m}\right)\Bigg|_{\Phi=1}
\end{aligned}$$

This, together with 27, gives us expression 17:

$$\frac{\partial}{\partial F_j^1}\left(\frac{\varphi^0_{A,j}}{\varphi^0_{A,m}}\right)\Bigg|_{\Phi=1} = -\frac{1-\delta}{\sigma-1}(\sigma-\varepsilon)\left(\underbrace{\frac{1}{P_j^1}\frac{\partial P_j^1}{\partial F_j^1}}_{+}-\underbrace{\frac{1}{P_m^1}\frac{\partial P_m^1}{\partial F_j^1}}_{+}\right)$$