Pricing Pollution: Asset-Pricing Implications of the EU Emissions Trading System*

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We study how the EU Emissions Trading System (EU ETS) affects the stock prices of regulated firms. Using historically representative ownership measures for more than 15,000 installations required to comply with the EU ETS, we construct a comprehensive data set of allocated allowances and verified emissions aggregated to the parent company. Our empirical strategy exploits the release of compliance information in the EU ETS, changes in the European carbon allowance price in combination with cross-sectional variation in the ratio of allocated allowances to verified emissions, and a high-frequency identification approach around regulatory announcements to rule out any potential confounding effects. Our findings point towards a robust influence of carbon prices on stock prices starting from Phase II of the EU ETS in 2008. We find that the transmission of carbon prices to stock prices is not limited to European firms that are relatively heavily regulated by the system but also applies to non-European firms that are regulated to a lesser extent. Whereas carbon pricing mainly affects company valuations via the profitability channel in Europe, our results lend support to a risk-based channel for non-European firms.

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1 Introduction

How does cap-and-trade carbon pricing affect the stock prices of regulated firms under the European Union Emissions Trading System (hereafter referred to as the EU ETS or "the system")? We empirically investigate this question in a comprehensive analysis of the system's asset pricing implications: our sample aggregates data on over 15,300 stationary[1] installations covered by the EU ETS, which we are able to link to returns of more than 1,200 listed firms that own at least one such stationary installation at any time in the system's history. Our sample includes firms with headquarters in the European Union and firms domiciled elsewhere, and our sample period spans all four operational phases of the EU ETS, starting from the system's inception in 2005 to – at the time of this writing – the latest completed compliance year in 2022.

We find that regulatory events in the system generate statistically significant and economically meaningful effects on the stock returns of regulated firms. Specifically, firms that fail to meet compliance standards of the EU ETS, namely to *"surrender annually the number of allowances corresponding to their emissions in the preceding year"* (European Commission, 2021), experience large negative cumulative abnormal returns of at least -2% in the five days around the announcement of compliance violations. Our findings indicate that market reactions are most negative for non-compliant firms that commit such a violation for the first time in their history ("first-time offenders") and virtually non-existent for non-compliant firms that have committed violations before ("repeat offenders"). Moreover, the announcement effect around EU ETS non-compliance becomes increasingly more negative as the severity of the compliance violation increases, as measured by the proportion of a firm's non-compliant emissions to its total verified emissions.

Our analysis further reveals that stock prices of regulated entities quickly respond to changes in the European carbon price and that the direction of this response depends critically on the number of allowances that a firm is allocated compared to the number of allowances that it needs to surrender. In our analysis, we quantify a firm's non-allocated allowances relative to verified emissions by its 'allocation shortfall'. Firms that are met with relatively lenient allocation, meaning they are provided with relatively large amounts of free allowances compared to their total needs respond much more positively to changes in carbon prices than competitors that rely to a greater extent on the purchasing of allowances to cover their emission needs. We show that the influence of allocation shortfall on the sensitivity to carbon price increases varies over the different operational phases of the EU ETS. Such a finding is intuitive since phases in the EU ETS have been characterized by vastly different allocation

[1] As of 2012, emissions from aviation are included in the ETS, meaning that aircraft operators are required to cover emissions for flights *within* the European Economic Area. Starting in 2024 emissions from the shipping sector will also be in the scope of the EU ETS. Our analysis however exclusively focuses on stationary installations.

plans and widely varying carbon prices. In the system's initial two phases, allocation shortfalls were generally much lower than in later phases. Besides differences in allocation, the European carbon price also fluctuated strongly across phases, thereby widely changing the financial impact of the system. Our findings paint a generally consistent picture where asset-pricing implications of the system depend heavily on the regulatory constraints the system imposes. However, we document that the system started to affect asset prices from as early as Phase II, when the EU ETS was still in its infancy and carbon prices were relatively low. Our empirical tests further reveal that the transmission of carbon price shocks to stock prices is not exclusively limited to companies of European domicile, but that stocks of non-European firms also similarly react to carbon price shocks. As European firms are typically more heavily regulated by the EU ETS than their non-European counterparts, this finding complements irecent observations that carbon pricing affects firms' returns via a profitability channel and additionaly supports the notion that investors take EU ETS-related information into account when discounting firm's cash flows. Our findings are relevant to policymakers since they point toward the widely varying implications that design choices in the system can have on the trading and pricing of stocks associated with entities regulated by the system.

Related literature. The efficiency of the EU ETS as an environmental policy tool has been extensively studied. Conclusions in this regard depend heavily on the period of study, with no pronounced effect of the EU ETS on carbon emissions in the first phase, moderately large effects in phase II, and large effects in later phases. Dechezleprêtre, Nachtigall, and Venmans (2023) causally estimate the system's impact by exploiting a design choice in the system to only include installations above certain industry-specific production thresholds. Using this quasi-experimental setting, Dechezleprêtre, Nachtigall, and Venmans (2023) attribute the EU ETS' introduction to about 10% of additional emissions reduction over the 2005 to 2012 period. Using a different setting, Bayer and Aklin (2020) similarly conclude that the ETS-regulated sectors emitted 11.5% less than they would have emitted without the EU ETS over phases I and II. Colmer et al. (2024) document carbon emissions reductions of between 14% to 16% for the same period using variation in industry eligibility in France. They do not find evidence for outsourcing to unregulated industries or countries, nor do they find negative effect on economic activity. Anderson and Di Maria (2011) report total emission abatements caused by the EU ETS in Phase I of about 2.8% for the EU. Most other research conducted in this area focuses on specific countries or sectors and either analyzes the system's effect at the aggregate level or the installation level. Ellerman and McGuinness (2008) find that the EU ETS is found to have reduced emissions in the UK's electricity sector by 17%. Känzig (2023) provides further evidence of the broader economic and environmental implications of the system using a novel identification approach that centers on the use of regulatory announcements. Other papers assess the distributional implications of the EU ETS. Martin et al. (2014) investigate whether the system's distribution of free allowances minimizes relocation risk of heavy emitters. They find that in general the allocation is inefficient, as the system tends to overallocate compared to an optimal allocation design with regards to this objective. This concern is also raised by Hepburn, Quah, and Ritz (2013). Calel (2020) finds negligible effects of the EU ETS on short-term emission reductions in the UK, but does find evidence increased R&D spending and patenting in low-carbon innovations.

The effect of the EU ETS on financial markets remains relatively understudied. The first empirical studies on the relationship between EU allowance prices and the stock market find that increasing carbon prices are associated with higher stock returns in Phase I of the EU ETS (Oberndorfer, 2009; Veith, Werner, and Zimmermann, 2009; Oestreich and Tsiakas, 2015; Zhu et al., 2018). This finding can mostly be attributed to the overallocation of allowances in Phase I that led to windfall profits, especially for the most carbon-intensive industries (Veith, Werner, and Zimmermann, 2009; Oestreich and Tsiakas, 2015). Most research in this area focuses on specific countries and sectors for only certain phases of the EU ETS. Oberndorfer (2009) studies the electricity sector in Phase I of the system and concludes that stock returns of power corporations and changes in carbon prices are positively related. Oestreich and Tsiakas (2015) study returns of German listed firms that are regulated by the EU ETS and conclude that the overallocation of the system's initial phases caused windfall profits that mostly benefited carbon-intensive firms. Ivanov, Kruttli, and Watugala (2023) show that for the Californian ETS, affected firms with high emissions are offered less favorable credit terms, including higher interest rates, particularly among private firms. A study by Bushnell, Chong, and Mansur (2013) finds that firms with higher carbon intensity obtained higher abnormal stock returns following the unexpected collapse of EU allowance prices in 2006. This effect was especially pronounced for firms that had a shortage of allowances. Brouwers et al. (2016) investigate announcement returns around the publication of emissions in the EUTL over Phases I and II of the EU ETS. Brouwers et al. (2016) document significant cumulative abnormal announcement returns during the first verification event of each phase, and no effects during other verification events. These results suggest that particularly the first verification event contains information that investors deem relevant for firm value.

A more recent literature studies the stock market implications of the EU ETS for a broad sample of firms using more appropriate causal identification strategies. Related works that can be included in this category are Bolton, Lam, and Muûls (2023), Millischer, Evdokimova, and Fernandez (2023), and Hengge, Panizza, and Varghese (2023). Similar as to our work, Bolton, Lam, and Muûls (2023) and Millischer, Evdokimova, and Fernandez (2023) rely on datasets constructed from EUTL data aggregated to the firm level. Using different methodologies, both these papers show that during Phase

III of the EU ETS, firms with lower allocations of allowances relative to their total emissions react more negatively to carbon price shocks. Bolton, Lam, and Muûls (2023) provide evidence that the EU ETS is affecting the profitability of these firms. Hengge, Panizza, and Varghese (2023) document that carbon policy surprises leading to increases in the carbon price have negative effects on stock prices, and that this effect is stronger for firms with higher carbon intensities. Hengge, Panizza, and Varghese (2023) further observe that the sensitivity to carbon policy shocks is stronger for firms that do not participate in EU ETS, lending novel support to an effect of carbon prices on firm's discount rates.

Contribution. A novel contribution of our work pertains to the stock market response to important ETS-related information. We show that the stock market responds to announcements of non-compliance with the EU ETS' regulations. Our event study analysis indicates that cumulative abnormal returns in the days surrounding the announcement of installation's EU ETS compliance decrease by at least 2%-points in the event of a mild violation that affects *at least* one of a firm's installations. The magnitude of this effect increases once we focus our definition of non-compliance on more severe violations that concern a greater fraction of the company's total verified emissions. Further analysis reveals that this effect is driven by firms that commit such a violation for the first time, hence suggesting that non-violation is already priced in by the market for "repeat-offenders". To the best of our knowledge, our paper is the first to consider the stock market's reaction to announcements on EU ETS non-compliance.

Second, we provide further evidence on the mechanism by which carbon pricing might affect asset prices. In contrast to prior papers however, we do not exclusively focus on Phase III of the EU ETS (2013 - 2020), but include all four operational phases of the EU ETS into our analysis. We show that the system had varying effects on the stock prices of regulated entities over its operational history, depending on specific characteristics and unique circumstances of each phase of the EU ETS. Furthermore, we document that the effects of carbon pricing on stock prices disseminate globally and across all firms and sectors rather than remain concentrated among more heavily regulated European firms and sectors. The fact that stock prices of European and non-European headquartered firms respond almost identically to changes in the EU ETS carbon price suggests that non-European stock prices are affected more so via a discount rate channel. Our analysis is the first to find evidence for such an effect.

A third contribution of our work is methodological. We are the first to consider historically representative ownership data in the construction of a comprehensive data set of allocated allowances and verified emissions at the parent company level for all the four operational phases of the EU ETS. Our sample construction starts by obtaining detailed information on installations participating in the EU

ETS via its dedicated reporting and monitoring tool, the European Union Transaction Log (EUTL). As the unit of observation in the EUTL is at the installation level, we follow an extensive procedure to match installations in the EU ETS to the listed companies that ultimately own them. To achieve this objective, we first combine various approaches to link installations in the EUTL with records of (subsidiary) companies in Bureau van Dijk's (BvD's) Orbis database. For more than 96% of the installations in our sample – representing almost 99% of combined emissions in the registry – we can establish such a link. Next, we expend considerable effort to match subsidiary firms to ultimate listed parent firms. Unlike most papers that make use of EUTL data at the installation level, we construct historically representative ownership links, meaning that we can trace ownership changes over time. This allows us to obtain precise estimates of aggregate allowances and emissions for the listed firms in our sample over time. We can thus explore the effects of exposures to the EU ETS on stock prices over all four operational phases in the EU ETS' history, rather than limit our focus to its most recent phases.

Institutional background on the EU ETS. Launched in 2005, the EU ETS forms the backbone of the EU's decarbonization strategy. The system covers more than 15,000 power stations and industrial facilities (hereafter referred to as stationary installations or simply installations) with total emissions amounting to 1.2 billion tonnes of CO_2-equivalent (CO_2-e) in 2022[2] – about 40% of total greenhouse gas emissions in the EU. The EU ETS has been the world's largest emissions trading scheme by covered emissions until 2020 and remains the world's largest scheme by traded allowances.[3] The system operates on the basis of *cap-and-trade*, where total emissions are 'capped' from above by the creation of a limited number of European Union allowances (EUAs) that grant a holder the right to emit 1 tonne of CO_2-e. By the end of each year's compliance cycle, typically at the end of April of the following year, installation operators have to "surrender" a sufficient quantity of allowances to account for that year's emissions. Allowance account holders within the EU ETS can buy and sell allowances on the market to meet their required emissions. Over time the cap is reduced so that the EU's climate ambitions can be targeted. If a regulated entity fails to surrender enough allowances by the end of the compliance cycle, heavy fines of more than €100 per ton of emissions are imposed.

The EU ETS has been significantly revised over its lifetime, with major revisions implemented in phases. Phase I ran from 2005 to 2007. In this phase, the system was first established. Many allowances were freely allocated and other features were being tested. In Phase II (2008-2012), the aviation sector was included, and information from the EU ETS was made accessible in the form of the EUTL.[4] Phase III (2013-2020) saw the introduction of a single, EU-wide, cap on emissions

[2] See https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

[3] China's national ETS, which started to operate in 2020, covers a larger number of emissions, but since it allocates a large portion of emissions freely, the amount of traded emissions remains lower than that of the EU ETS.

[4] Before its introduction in 2008, a similar registry named the Community Independent Transaction Log functioned as

rather than country-specific caps, and a steep increase in the number of auctioned rather than freely allocated allowances. Currently, in Phase IV (2021-2030), the cap has been reduced and made to automatically decrease every year. An overview of the total emissions covered by the firms in our sample, as well as the amount of emissions allowances that have been allocated freely, is presented in Figure 1.

The price of EUAs has fluctuated significantly over the different phases of the system. Figure 2 plots the daily settlement price for the front EUA future from April 2005 to the end of March 2023. During Phase I, the price converged towards zero due to the vast overallocation allowances, coupled with uncertainty regarding the national allocation plans of participating countries and the design choice of the European Commission to not allow the inter-temporal trading of EUAs from Phase I to Phase II (also known as "banking" of allowances). National allocators were granted less leeway in their allocation plans for Phase II (2008-2012). Combined with strong economic growth expectations at the beginning of 2008, the carbon price initially rose. However, the weakening economic climate at the onset of the Great Financial Crisis and the subsequent recession caused the EUA price to again decrease severely. Some of these shortcoming were addressed in Phase III (2013-2020). Demand for EUAs became stronger, as much less allowances were allocated freely. An automatic emissions reduction mechanism was implemented, which will reduce the total emissions cap by 1.74% every year. In the second half of Phase III, the EUA price steadily rose to above €40 per tonne of CO_2-e. Phase IV saw the carbon price skyrocket, reaching values of above €100 for the first time in February 2023. However, varying expectations about future demand and uncertainty about regulations have also led to highly volatile carbon prices in 2022 and 2023.

2 Data

To investigate how the EU ETS drives asset prices, we collect verified emissions and allocated allowances for all stationary installations covered by the EU ETS. We then link these installations to parent firms – paying close attention to historically accurate current ownership structures – thus creating a data set of emissions and allowances at the company level. To this end, we combine information on (i) emissions and allowances of stationary installations from the European Union Transaction Log (EUTL), (ii) subsidiary firm records in Bureau van Dijk's Orbis Global, (iii) corporate ownership structures from Bureau van Dijk Orbis Global, (iv) stock returns and corporate data from Refinitiv Eikon, and (v) prices of futures on EU Emissions Allowances from FactSet.

its predecessor throughout Phase I of the EU ETS.

2.1 European Union Transaction Log

The EUTL forms the central reporting system of the EU ETS. The EUTL provides detailed information on the regulated entities active in the EU ETS and their compliance with the system's regulations. Besides, all transactions between participants in the system are recorded and reported through the EUTL with a delay of three years.

Allowances and emissions. We start by obtaining information on all installations, verified emissions, and allocated allowances in the EU ETS via the webpage of the EUTL.[5] We merge this data with the `'List of Operators in the EU ETS'`, which contains company-specific information on the operator holding accounts associated with each installation. Through this file, we obtain the account holder of each installation, company registration information, the national regulator under which it operates, a description of its main business activities, and location details. Importantly, we also obtain the installation's parent company, which we use in subsequent steps to establish a link with company records in Bureau van Dijk's Orbis. We download information from installations operating in all countries participating in the EU ETS, including EU countries and the United Kingdom, Switzerland, Norway, Sweden, and Finland.[6] Lastly, we obtain compliance data that indicates whether each installation was able to comply with the requirement of surrendering allowances equal to verified emissions by the end of April in the year following the compliance year. This information is recorded in the form of a compliance code. In case this compliance code corresponds to an insufficient amount of surrendered allowances (code B), a missing registration of the installation's verified emissions (code C), or a revision by the national emissions authority of the stated emissions that causes surrendered emissions to fall below verified emissions (code D), we register the installation as having failed to meet the compliance requirements.[7] When aggregating compliance information to the firm level, we regard a firm as not in compliance for a specific year if at least some portion of its total emissions come from non-compliant installations with compliance codes equal to B, C, or D.

[5] Accessible at https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/union-registry_en.

[6] The UK left the EU ETS in 2021 as a result of Brexit, and Switzerland integrated its own ETS with the EU ETS in 2020. We make sure that firms headquartered in the UK and Switzerland are only included in our sample before 2021 and after 2020.

[7] Compliance code B indicates that "*the number of allowances ... surrendered by 30 April is lower than verified emissions*", compliance code C indicates that "*verified emissions were not entered until April 30*" and compliance code D indicates that "*verified emissions were corrected by competent authority after April 30 of year X. The competent authority of the Member State decided that the installation is not in compliance for year X-1*" (see https://ec.europa.eu/clima/ets/allocationComplianceMgt.do?languageCode=en). Compliance code X indicates a failure to comply due to a temporary suspension of the surrender process (e.g., due to technical failure) and is, therefore, not included in our definition of non-compliance since it falls beyond the control of the installation's operator.

2.2 Corporate Ownership

We follow several steps to match installation-level data from the EUTL to parent-company-level outcomes, such as stock price returns. In the first step, we pair installations to subsidiary firms in Burea van Dijk's Orbis database. To do so, we rely on two approaches. First, we match information on company names, account holder names, and installation names (in that order, respectively) from the EUTL to firms in Bureau van Dijk, relying on BvD's search algorithm to establish such matches. We are careful in this step to only search for company records within the country in which the installation is located to minimize the risk of false positives. Furthermore, we thoroughly inspect the matching outcomes and delete erroneous links. Second, we make use of the linking files generously provided by Letout (2022). These linking tables make use of national registration numbers to match industrial installations to firms in Bureau van Dijk. These combined approaches result in a registered subsidiary firm for about 96.1% of the installations in the EUTL, representing over 98.7% of total CO_2 emissions in the EU ETS. The few installations for which we do not find a registered subsidiary firm tend to be (local) government facilities such as hospitals and universities that are large enough to be regulated under the system but that are typically not associated with a registered company in Orbis.

Next, we match subsidiary firms to parent companies so that we can aggregate emissions and allowances across installations owned by the same (listed) parent companies. Since our sample period covers the entire lifespan of the EU ETS from 2005 to 2024, we want to keep track of historically accurate ownership chains so that for each year of the EU ETS, we can accomplish an accurate representation of aggregated emissions and allowances at the parent company. While Orbis reports a Global Ultimate Owner for all subsidiary firms in its database for exactly this purpose, this information is only based on current ownership structures and retrospectively revised whenever an ownership change occurs. The GUOs, as reported by Orbis, therefore, do not provide a historically accurate ownership link. We circumvent this issue by relying on an alternative, more elaborate procedure that is adapted from Jaraitė et al. (2013). In short, the procedure works by iteratively obtaining the shareholders for each subsidiary firm obtained in the first step. We then query Bureau van Dijk for any potential shareholder of all the shareholders obtained via the prior query. We continue to download shareholder information until no shareholders can be found. Once we do not find any shareholders, we assume to have reached the ultimate owner in the ownership chain. Once we have obtained these data, we follow several data cleaning steps to deal with (i) non-numeric shareholdings reported (e.g., "MO" for majority-owned), (ii) missing data, (iii) duplicated data, (iv) non-corporate ownership, and (v) non-publicly-listed *ultimate* ownership. Our cleaned ownership file includes 209,384 unique ownership links, that is, unique combinations between a subsidiary firm and a shareholder, for 19,810 unique subsidiaries with 18,542 unique shareholders.

This procedure is laid out in detail in Appendix B. Table B1 provides a summary of the matching outcomes in tabular format.

2.3 Stock Returns and Corporate Characteristics

Stock Returns We download daily stock returns (in local denomination) from Refinitiv Eikon for the firms in our sample. To ensure a sufficient level of liquidity for the stocks in our sample, we require that stocks be traded on at least half of trading days.[8] We further winsorize returns at the 0.5% and 99.5% levels to mitigate the effect of extreme outliers. Table 6 reports descriptive statistics on the stock returns considered: the representative stock in our sample has a mean daily return of 0.041% and a daily volatility of 2.45%.

We further download daily returns on developed and European factor portfolios from Kenneth French's website.[9] We obtain returns series for the market, size, value, profitability, investments, and momentum portfolios.

Corporate Data. Monthly corporate data were obtained from Refinitiv Eikon. We download information on each firm's return on equity, return on assets, book-to-market ratio, leverage ratio, property, plant & equipment to assets, and investment to assets. Further details are provided in Table A1 in Appendix A.

2.4 Other Data

EU Allowances Prices. We obtain daily settlement prices for futures on EU allowances that are traded on the European Climate Exchange (ECX) and the European Energy Exchange (EEX). We base our analysis on futures prices rather than spot prices because the carbon futures market tends to be more liquid (Känzig, 2023). All futures prices were downloaded from FactSet. Specifically, we retrieve daily settlement prices of the InterContinental Exchange's (ICE's) ECX front future contract, the NDEX EEX near-term contract, the NDEX EEX continuous contract, and the EUCARB spot contract.[10] The ICE ECX front future has the longest history, starting in April 2005. The front future trades in the nearest expiration date, and is typically the most liquid. We therefore use it as the baseline carbon price in all our analyses. Besides, Stefan and Wellenreuther (2020) show that, in particular, futures prices from ICE dominate price discovery in the carbon market. In the remainder

[8] Some firms in our sample trade on markets that are active on weekends. We remove these observations as they might cause problems in combination with our fixed effects regressions. We do, however, keep the returns of such stocks if they occur on weekdays.

[9] Available at: https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

[10] Respectively with FactSet IDs 'ECF-FDS', 'DEAU-FDS', 'ECF00-NDEX', and 'EUCARB-FDS'

of this paper, the daily return on the ICE ECX front future from days $t-1$ to t is denoted by r_t^{EUA}. Prices for the NDEX continuous contract and the EUCARB spot contract became available in early 2008, while the NDEX EEX near-term was launched halfway through 2010. Figure A1 in Appendix A plots the different carbon prices over the sample period. Table A2 reports pairwise correlation coefficients between the different EUA price proxies. As all reported correlation coefficients are above 96%, the choice of baseline carbon price proxy is unlikely to influence our results.

Corporate Emissions. We collect information on corporate greenhouse gas emissions from S&P's Trucost. These data are either publicly reported (for example, via a sustainability report) or estimated by Trucost's proprietary model. Trucost follows the Greenhouse Gas Protocol when reporting on emissions.[11] The Greenhouse Gas Protocol separates emissions into three 'scopes': (i) Scope 1 emissions include the direct emissions occurring in a company's production process; (ii) scope 2 emissions are the indirect emissions associated with the purchase of electricity, heat, or steam; and (ii) All other emissions taking place in a company's value chain are accounted for under scope 3. We sum scope 1 and 2 emissions into a combined scope 1&2 measure. To construct a measure of the extent to which a firm is exposed to the EU ETS, we divide total EU ETS verified emissions by total (reported or estimated) scope 1 emissions (see

Analyst Estimates. To estimate the cost of capital for the firms in our sample, we rely on earnings forecasts from the Institutional Brokers' Estimate System (hereafter referred to as 'IBES'). Our sample is based on monthly earnings forecasts for the coming (FY1) and forthcoming (FY2) fiscal periods and the estimated long-term growth rate in earnings. We collect accounting as well as stock price data from Compustat North America and Compustat Global. To be included in our sample, we require the availability of data on monthly closing prices, shares outstanding, dividends, net income, book value of equity, and GICS industry classification. We then compute the implied cost of (equity) capital (ICC) following Gebhardt, Lee, and Swaminathan (2001) (GLS). Further details on this calculation are provided in Appendix C.

Carbon Policy Surprises. Känzig (2023) proposes a high-frequency event study around price changes during regulatory EU ETS updates to causally estimate the effects of carbon prices. To this end, we obtain a list of 81 regulatory events from January 2011 to December 2018 from Känzig (2023). We supplement this list with 15 events identified by Hengge, Panizza, and Varghese (2023) and further expand it with 30 events from before 2011 and with eight events after 2021, which we collected from press releases published on the website of the European Commission. Table A4 in the Appendix provides an overview of the identified event announcements. Following Känzig (2023), the Carbon Policy Surprise is given by the daily percentage change in the EUA futures price on

[11] https://ghgprotocol.org.

regulatory event days and by zero otherwise. Formally:

$$\text{Carbon Policy Surprise}_t = r_t^{\text{EUA}} \times \mathbb{1}_t^{\text{Regulatory Event Day}}, \tag{1}$$

where r_t^{EUA} is the daily return on the EUA front future and $\mathbb{1}_t^{\text{Regulatory Event Day}}$ is an indicator variable equal to one on days where a regulatory update to the EU ETS is announced and equal to zero on all other days. Figure 3 presents a graphical overview of Carbon Policy Surprises over our sample.

2.5 Variables Constructed from EUTL Data

Verified Emissions. For each installation j owned by listed parent company i in compliance year t we sum the product of the ownership of parent company i in the subsidiary company linked to installation j with the verified emissions of installation j over compliance year t over the number of installations $N_{i,t}$ owned by listed parent company i at the end of compliance year t

$$\text{Verified Emissions}_{i,t} = \sum_{j=1}^{N_{i,t}} \text{Ownership}_{i,j,t} \times \text{Verified Emissions}_{i,j,t}, \tag{2}$$

where $N_{i,t}$ denotes the number of installations at least partially owned by parent company i at the end of year t, $\text{Ownership}_{i,j,t}$ refers to the total (direct and indirect) share ownership of listed parent company i in installation j at the end of compliance year t and $\text{Verified Emissions}_{i,j,t}$ denotes the number of verified emissions of installation j over the compliance year t.

Total Allocation. We perform a similar aggregation for allocated allowances at the parent company level

$$\text{Allocated Allowances}_{i,t} = \sum_{j=1}^{N_{i,t}} \text{Ownership}_{i,j,t} \times \text{Allocated Allowances}_{i,j,t}, \tag{3}$$

where variables are defined as in Equation (2) before and $\text{Allocated Allowances}_{i,j,t}$ denotes the number of allocated allowances of installation j over compliance year t.

Allocation Shortfall. Allocation Shortfall represents the fraction of non-allocated allowances as a percentage of verified emissions in year $t-1$. A high allocation shortfall indicates that the firm needs to buy allowances in the open market to cover its annual emissions. In contrast, a firm with a negative allocation shortfall has an excess of allocated allowances and could sell them in the market at will.

$$\text{Allocation Shortfall}_{i,t} = 1 - \frac{\text{Allocated Allowances}_{i,t}}{\text{Verified Emissions}_{i,t}} \tag{4}$$

We require firms to have at least some verified emissions in year t before we calculate their Allocation Shortfall for that year. This measure of Allocation Shortfall is bounded from above by one and unbounded from below, taking on highly negative values for firms that have allocated allowances much higher than emissions. Since we do not want this variable to be too much influenced by extreme values, we cap its range from below by a value of -1. This limits the maximum attainable variation in Allocation Shortfall to at most two units.[12]

Figure 1 displays the combined emissions in millions of tonnes of CO_2-equivalent that can be attributed to the firms in our sample over the lifetime of the EU ETS. Note that these emissions are adjusted for ownership percentages, e.g., if a parent company ultimately owns 50% of a regulated installation, one-half of that installation's verified emissions will be attributed to the parent company. At the system's inception, our sample represents roughly 900 million tonnes of CO_2-e. Total emissions grew considerably over the first few years of the sample and then started to gradually decrease after 2009. The figure also shows the number of allocated allowances for all firms in our sample. As can be seen clearly from the graph, total emissions were almost fully covered by allocated allowances in Phases I and II. Starting in Phase III, a much larger portion of allowances had to be acquired by regulated entities, and the total number of allocated allowances has since continuously been reduced. Table 3 and Table 4 provide a similar overview but break down the trend by industry inclusion. Table 4 reports allocated allowances and emissions in relative terms (as a fraction of total emissions and allowances across all industries within each phase), while Table 3 reports emissions and allowances in absolute numbers. The vast majority of accumulated emissions over the EU ETS's history resulted from power generation (Utilities), followed by materials construction and energy provision. Particularly, the utility sector has seen allocated allowances reduced since firms in these sectors face limited international competition. Firms in more globally competitive industries, such as in the Materials sectors, have been met with more lenient allocation plans.

Long Allocation vs. Short Allocation. Since the effects of a carbon price shock could be asymmetric for firms that have many emissions compared to firms that are short emissions, we construct two dummy variables that capture opposite exposures. We set the variable $\mathbb{1}(\text{Long Allocation})_{i,t}$ equal to one if $\text{Allocation Shortfall}_{i,t}$ is equal to or below the 25^{th} percentile of the distribution of Allocation Shortfalls over all firms at time t and equal to zero otherwise. Similarly, $\mathbb{1}(\text{Short Allocation})_{i,t}$

[12] In unreported robustness tests, we confirm that this choice does not influence our results. As the incidence of firms with Allocation Shortfalls below -1 is low, this choice mostly impacts the interpretation of the estimated coefficients on Allocation Shortfall but not its overall inference. Capping the variable from below effectively results in a winsorization of the distribution below the 3.7^{th} percentile.

equals one if Allocation $\text{Shortfall}_{i,t}$ is equal to or above the 75^{th} percentile at time t.

EU ETS Exposure. We construct a proxy of the extent to which a firm is exposed to the system by dividing EU ETS-regulated emissions by scope 1 emissions which are estimated or reported by Trucost.

$$\text{EU ETS Exposure}_{i,t} = \frac{\text{Verified Emissions}_{i,t}}{\text{Scope 1 emissions}_{i,t}} \tag{5}$$

Hence, *EU ETS Exposure* captures the fraction of a firm's total scope 1 emissions that are regulated under the EU ETS. A firm with most of its production in the EU would have EU ETS exposure close to 1, while a firm that outsources most of its emissions to non-regulated countries would hold zero exposure.

2.6 Descriptive Statistics

Table 1 and Table 2 show the number of firms in our sample belonging to each industry sector. Most firms in our sample are operating in the Materials, Industrials, Consumer Staples, Consumer Discretionary, and Utilities sectors. This is expected since these industries have larger emissions due to the industrial nature of their operations. However, our sample also includes a large number of firms in traditionally less emission-intensive industries that nonetheless own operations covered by the EU ETS. We group Information Technology, Communication Services, and Real Estate in one category since their relative infrequency could lead to problems in our later regression specification if it includes industry-fixed effects. An overview of the 20 firms with the highest emissions covered by the EU ETS for the 2022 compliance year is provided in Table 5. The Polish electricity provider PGE Polska tops the list with more than 70 million tonnes of CO_2-e in verified emissions. German electricity provider RWE is second with a little over 64 million tonnes of emissions. Allocation shortfalls in this set of firms range from 13.75% (Heidelberg Materials) to 99.83% (Public Power Corporation of Greece). The financial impact of this shortfall expressed in monetary terms using end-of-2021 allowance prices varies between €235 million for Heidelberg Materials to €5.5 billion for PGE Polska.

Descriptive statistics on the variables used in our analysis are reported in Table 6. Our main sample includes almost 2.8 million daily returns on more than 1,000 listed firms that own installations regulated by the EU ETS. The mean (median) daily return over the sample period from the beginning of 2005 to the end of 2023 is 0.041% (0%) with a mean daily return volatility of 2.19% (1.95%). The average firm in our sample trades at a market capitalization of €4 billion, yet the distribution is highly skewed to the right, with the 99^{th} percentile of market capitalization at over €190 billion.

Panel B of Table 6 reports on ETS-related statistics. The average regulated firm emits annually about 1.8 million tonnes of CO_2-equivalent, of which 1.3 million tonnes of CO_2-e have been freely allocated allowances. The representative firm is short 19.6% of its ETS-regulated emissions, which in monetary value represents 0.2% of its market capitalization. The monetary value of the allocation shortfall, as represented by the Carbon Tax Rate, represents at least 10% of market capitalization in the 1% highest-regulated entities.

3 Methodology

3.1 Stock market response to EU ETS information releases

Our first objective is to examine whether stock markets react to the announcement of important information in the EUTL. To do so, we estimate cumulative abnormal returns (CARs) during the 20-day window around these announcements. In particular, we study the release of information on the "*naming and shaming*" of installations that fail to meet the requirement of surrendering emissions allowances equal to their verified emissions by the compliance deadline via the EUTL. Information on non-compliance was typically published around half of May of the year following the compliance year in phases I and II of the ETS and is being released at the beginning of May in its most recent two phases. In all years this information was disseminated at noon CET. Table A3 in the Appendix reports detailed information on publication dates and the EU ETS compliance cycle.

We start our analysis by investigating how the stock market reacts to announcements of non-compliance with the EU ETS' obligation to surrender sufficient quantities of emissions allowances. To this end, we estimate a standard event study regression

$$\begin{aligned} \text{CAR}_{i,\tau,y} = & \sum_{\tau=-10}^{10} \beta_\tau \mathbb{1}_{\tau,y}^{\text{Event Day} = \tau} \times \mathbb{1}_{i,y}^{\text{Non-Compliant}} + \sum_{\tau=-10}^{10} \gamma_\tau \mathbb{1}_{\tau,y}^{\text{Event Day} = \tau} \\ & + \sigma_{i,y} + \varepsilon_{i,\tau,y} \end{aligned} \tag{6}$$

where $\text{CAR}_{i,\tau,y}$ represents the cumulative abnormal return for firm i accumulated over the event days from -10 to τ and estimated with respect to the CAPM model. The index y indicates the compliance year, as compliance is announced annually and firms can be compliant or non-compliant in different years. τ denotes a normalized event date and represents the number of days relative to the announcement date. The indicator variable $\mathbb{1}_{i,y}^{\text{Non-Compliant}}$ equals 1 if firm i owns at least one installation that fails to surrender allowances equal to verified emissions in compliance year y. In all other cases, we set $\mathbb{1}_{i,y}^{\text{Non-Compliant}}$ equal to zero. An industry-by-year fixed effect denoted by $\sigma_{i,t}$ is included in the estimation to control for time-varying unobserved effects that cluster at the industry level. We cluster standard errors by firm and year to account for serial correlation at the firm level.

To assess the robustness of our findings, we also estimate Equation (6) for CARs that have been estimated with the Carhart (1997) momentum model and the Fama and French (2015) 5-factor model augmented by the Carhart (1997) momentum factor, denoted respectively by $\text{CAR}_{i,t}^{C4F}$ and $\text{CAR}_{i,t}^{\text{FF4F+Mom}}$. We exploit two further modifications to Specification Equation (6) to more deeply investigate stock market reactions in response to non-compliance announcements. First, we disentangle stock market reactions to announcements of non-compliance for firms that are reported to be non-compliant for the first time in their history and for firms that have been non-compliant before, as arguably the first instance of non-compliance reveals more information to the market. Second, we analyze if the effect becomes stronger by increasing the severity of violations. To this end, we explore stricter definitions of non-compliance that indicate compliance violations of larger severity by increasing the minimum emissions threshold $q \times 100\%$ at which we regard firms as non-compliant over the interval $(0, 1]$ by step sizes of 0.1. For example, if q is set equal to 0.3, then we define non-compliant firms as firms that own at least one installation that fails to surrender allowances equal to verified emissions and the total verified emissions of non-compliant installation(s) represents at least 30% of the firms total verified emissions.

3.2 Heterogeneous Exposure to Carbon Price Shocks

To empirically estimate how carbon pricing is affecting the stock returns of regulated firms, we adopt a specification similar to Millischer, Evdokimova, and Fernandez (2023) and Bolton, Lam, and Muûls (2023). Since we expect that sensitivity to carbon prices varies with the extent to which a firm is granted allowances, our main variable of interest lies in the interaction term between allocation shortfall and the carbon price change. We expect the coefficient on this interaction term to be negative since firms with a larger shortage of allowances are expected to be more negatively affected by increasing carbon prices. We thus estimate

$$\text{r}_{i,t}^{e} = \alpha + \beta_0 \text{AS}_{i,t} \times r_t^{\text{EUA}} + \beta_1 \text{AS}_{i,t} + \lambda X'_{i,t\text{-}1} + \sigma_{i,t} + \mu_t + \varepsilon_{i,t} \tag{7}$$

where $\text{r}_{i,t}^{e}$ denotes firm i's return in excess of the risk-free rate at day t, r_t^{EUA} refers to the daily change in the settlement price of the EUA front futures contract traded on ICE, $\text{AS}_{i,t}$ is the Allocation Shortfall defined as firm i's proportion of non-allocated allowances to verified emissions in compliance year t and captures the extent to which firm i is reliant upon purchased allowances rather than allocated allowances to cover its emissions, $X_{i,t-1}$ is a vector of (lagged) control variables, $\sigma_{i,t}$ denotes an industry-by-year fixed effect, and importantly μ_t denotes a date fixed effect. The regression does not include the direct effect of r_t^{EUA} as it is subsumed by the date fixed effect μ_t and can therefore not be estimated. The inclusion of a date fixed effect is important in our identification strategy since it controls for potential confounding factors that simultaneously affect stock returns and allowance prices, such as macroeconomic forces. We cluster standard errors at the firm and day levels because returns are highly correlated within dates and our treatment variable differs mainly across firms. The vector of control variables $X_{i,t\text{-}1}$ includes lagged characteristics that are known to affect stock prices, mainly the natural logarithm of market capitalization, the return on equity, tangibility as proxied for by property, plant & equipment to assets and investment to assets, the book-to-market ratio, firm leverage, and the firm's prior-month market beta. All accounting variables are winsorized at the 0.5% and 99.5% tails to minimize the effect of outliers and data errors.

In theory, exposure to carbon price shocks need not be linear in our measure of Allocation Shortfall. It could be that depending on the unique circumstances of a certain EU ETS phase, positively exposed firms are differently affected than negatively exposed firms. To test for these potential asymmetries, we adopt a modification to Equation (7) similar to the specification in Bolton, Lam, and Muûls (2023)

$$\begin{aligned} \mathrm{r}^e_{i,t} = \alpha &+ \beta_0 \mathbb{1}_{i,t}^{\text{Short Allocation}} \times r_t^{\text{EUA}} + \beta_1 \mathbb{1}_{i,t}^{\text{Long Allocation}} \times r_t^{\text{EUA}} + \beta_2 \mathbb{1}_{i,t}^{\text{Short Allocation}} \\ &+ \beta_3 \mathbb{1}_{i,t}^{\text{Short Allocation}} + \lambda X'_{i,t\text{-}1} + \sigma_{i,t} + \mu_t + \varepsilon_{i,t} \end{aligned} \tag{8}$$

where all variables are defined as in Equation (7), except for $\mathbb{1}_i^{\text{Short Allocation}}$ and $\mathbb{1}_i^{\text{Long Allocation}}$, which are indicator variables that indicate whether a firm's allocated emissions relative to verified emissions are below respectively above a threshold. These thresholds are determined by the 25$^{\text{th}}$ and 75$^{\text{th}}$ percentiles of the distribution of allocated emissions relative to verified emissions. Note that these percentiles are defined cross-sectionally and therefore vary over time, to capture the changing regulatory environments of the various EU ETS phases. Elsewhere, the estimation strategy for Specification Equation (8) is similar to that of Specification Equation (7).

3.3 Alleviating Endogeneity Concerns: A High-Frequency Event Study Approach

A potential endogeneity concern in our setting is that allowance prices are impacted by the same macroeconomic factors that influence stock returns. Our baseline specification includes time-fixed effects to absorb such macroeconomic influence. However, this endogeneity might still be problematic if the macroeconomic factors affect firms with differing EU ETS exposure differently. Känzig (2023) circumvents this issue with a high-frequency identification approach. More specifically, Känzig (2023) constructs a Carbon Policy Surprise series that reflects the change in the carbon price on days on which regulatory updates of the EU ETS are communicated. As the carbon policy surprise reflects a price change around the event, it must represent an unanticipated demand or supply shock for EUAs. To the extent that the state of the economy is already priced at the time of the announcement and does not change within the relatively tight window around it, endogeneity concerns can be plausibly ruled out (Känzig, 2023).

We can then estimate how the effects of price shocks in the European carbon price on stock returns differ for companies that have differing allowance exposures by estimating a specification akin to that of Hengge, Panizza, and Varghese (2023) and Millischer, Evdokimova, and Fernandez (2023)

$$\begin{aligned} \mathrm{r}^{e}_{i,t} = \alpha &+ \beta_0 \ \mathrm{AS}_{i,t} \times r^{\mathrm{EUA}}_t \times \mathbb{1}^{\text{Regulatory Event Day}}_t + \beta_1 \ \mathrm{AS}_{i,t} \times r^{\mathrm{EUA}}_t \\ &+ \sigma_i + \phi_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{9}$$

where $\mathrm{r}^{e}_{i,t}$ denotes firm i's return in excess of the risk-free rate on day t, $\mathrm{AS}_{i,t}$ is the firm's Allocation Shortfall, $\mathbb{1}^{\text{Regulatory Event Day}}_t$ is an indicator variable equal to one if day t is a Känzig (2023) regulatory event day and equal to zero otherwise (the term $r^{\mathrm{EUA}}_t \times \mathbb{1}^{\text{Regulatory Event Day}}_t$ is the Carbon Policy Surprise index shown in Figure 3), r^{EUA}_t is the daily return on the EUA futures' price, σ_i is a firm fixed effect, and $\phi_{i,t}$ is an industry-by-year fixed effect. The coefficient β_1 can be interpreted as the effect of a 1% shock in carbon prices on days when no regulatory updates are announced. β_0, on the other hand, represents the difference in this effect between non-regulatory days and regulatory event days. If the endogeneity concerns discussed in this section are valid, we would expect β_1 to be significantly different from zero and positive, while β_0 would be significantly different from zero and negative.

3.4 Mechanism: Cash-Flows vs. Discount Rates

Our empirical design so far has revolved around the question: does carbon pricing influence the stock prices of regulated firms?' Our next focus will lie on the underlying mechanism: *"if there is indeed such an effect, then why do stock prices respond?"* Stock prices move due to at least one of two reasons. Either there is news about the profitability of a firm, which affects expected dividends, or there is news about the risk of a firm, which affects valuation via the *discounting* of expected dividends. We proxy for changes in the discount rate using firm-level estimates of implied costs of capital (ICC). Details on this calculation are provided in Appendix C. Changes to cash flows are proxied for by using quarterly reported return on equity (ROE) values. We investigate the mechanism through which the EU ETS affects stock prices by changing the response variable in our baseline specifation Equation (7)

$$\begin{aligned}\Delta\text{ROE}_{i,t:t+12} &= \theta_0 + \theta_1 \text{AS}_{i,t} \times r_t^{\text{EUA}} + \theta_2 \text{AS}_{i,t} + \lambda X'_{i,t\text{-}1} + \sigma_{i,t} + \mu_t + \varepsilon_{i,t} \\ \Delta\text{ICC}_{i,t:t+12} &= \gamma_0 + \gamma_1 \text{AS}_{i,t} \times r_t^{\text{EUA}} + \gamma_2 \text{AS}_{i,t} + \lambda X'_{i,t\text{-}1} + \sigma_{i,t} + \mu_t + \varepsilon_{i,t}\end{aligned} \tag{10}$$

where $\Delta\text{ROE}_{i,t:t+12}$ is the change in the firm's return on equity over the 12-months following the shock to the carbon price and $\Delta\text{ICC}_{i,t:t+12}$. Our coefficient of interest lies again in θ_1 and γ_1, which represents the difference in the 1-year ahead change in ROE and ICC following a 1% increase to carbon prices for each unit increase in allocation shortfall. Given that we expect that changes in the carbon prices affect negatively firms with higher allocation shortfalls, our prior is that θ_1 is negative and γ_1 is positive. Note that all other fixed effects and control variables remain unchanged.

4 Results

4.1 Event study analysis

In this section, we provide event studies around the release of compliance information. Our objective is to assess whether and how the market reacts to important information about a firm's compliance with regulation. An installation regulated by the EU ETS is required to surrender allowances equal to its verified emissions by April 30$^{\text{th}}$ of the year following the compliance year. The installation's national regulator could deem the installation non-compliant if it fails to surrender a sufficient quality of allowances, if it fails to report verified emissions, or if the regulator decides that the reported emissions cannot be verified. Such compliance information is reported via the EUTL, typically halfway around May (Phases I and II) and at the beginning of May (Phases III and IV). Table A3 in the Appendix provides exact compliance announcement dates. We obtain Cumulative Abnormal Returns (CARs) for a 20-day window around the announcement by estimating variations on the model in Equation (6). Our baseline CARs are calculated for the CAPM market model. For robustness, we repeat the analyses for CARs estimated concerning the Carhart (1997) 4-factor mode and the Fama and French (2015) 5-factor model augmented by the Carhart (1997) momentum factor.

4.1.1 Stock market reaction to EU ETS non-compliance

To explore how the stock market responds to announcements of EU ETS non-compliance, we estimate the event study regression in Equation (6). Since compliance is reported at the installation level, we conduct the following aggregation to study its return effects at the firm level. Specifically, we define firm i to be non-compliant for year $t-1$ if firm i owned at least one installation at the end of December in year t that failed to surrender allowances equal to verified emissions by April 30$^{\text{th}}$ of year $t+1$. Our definition of non-compliance encompasses three cases: (i) the installation surrendered a number of allowances lower than emissions, (ii) the verified emissions were not entered by the installation at the reporting deadline, and (iii) the reported emissions were corrected by the national regulator which caused the number of surrendered allowances to be lower than the number of verified emissions. If non-compliance constitutes an event that is efficiently priced by market participants and if such information is at once released on the event date, then we expect that cumulative abnormal returns stay insignificantly different from zero for the ten days before the announcement, become negative on the announcement date and subsequently remain stable in the ten days post announcement.

Figure 4 presents stock market reactions to announcements of EU ETS non-compliance. In the eight days before the announcement, the CAR hovers around zero, providing reassurance that non-compliant firms and compliant firms are subjected to similar market forces before treatment. During the one day before the announcement and two days following the announcement, non-compliant firms underperform compliant firms by a statistically significant 1.8%. The stock market thus responds negatively to these announcements, indicating that a failure to comply with the system's regulation is observed by the market as a relevant indicator of lower future profitability and/or increased risk exposure. The fact that the negative return effect starts to occur a day before the announcement is somewhat surprising and suggests that compliance information already reaches the market a day prior to being released via the EUTL. Furthermore, the reduction of shareholder value in response to a compliance violation occurs gradually upon the release of compliance data. This could be explained by the fact that it takes time for the market to fully comprehend the extent of the valuation and the implications on firm value. We show in Figure A2 in the Appendix that our conclusions are not influenced by the choice of factor model used in the calculation of abnormal returns. Figure A2 displays CARs with respect to the Carhart (1997) 4-factor model and the Fama and French (2015) 5-factor model augmented by the Carhart (1997) momentum factor. The stock market reaction in response to announcements of non-compliance remains robust to the consideration of alternative factor models.

4.1.2 Further sub-sample analysis

First-time vs. repeat offenders. Now that we have established the impacts of non-compliance announcements on firm value, we provide additional subsample analysis to further strengthen our understanding of this market response. We first compare instances of non-compliance for firms that commit an EU ETS violation for the first time in their history ("first-time offenders") to those of firms that have been non-compliant before ("repeat offenders"). One could argue that the release of non-compliance for first-time offenders comes as a greater shock to the market since, for repeat offenders, non-compliance might be partially expected. Figure 5 compellingly shows that the market response is limited to first-time offenders. No significant market reaction is observed for firms classified as repeat offenders. This observation carries broader implications since it hints towards a risk-based explanation of the non-compliance announcement effect on firm valuation, as the financial impacts of the compliance violation on the firm's profitability in the form of imposed fines would be similar for repeat offenders as for first-time offenders.

Severity of compliance violation. Second, we analyze if the effect becomes stronger by increasing the severity of violations. To this end, we explore stricter definitions of non-compliance that indicate compliance violations of larger severity by increasing the minimum emissions threshold $q \times 100\%$ at which we regard firms as non-compliant over the interval $(0, 1]$ by step sizes of 0.1. For example, if q is set equal to 0.3, then we define non-compliant firms as firms that own at least one installation that fails to surrender allowances equal to verified emissions, and the total verified emissions of non-compliant installation(s) represents at least 30% of the firm's total verified emissions.

Figure 6 shows that cumulative abnormal returns over 3-day, 5-day, and 10-day windows around the non-compliance announcements become more negative for firms that are involved in more severe compliance violations. For example, the market response in the 5-day window around the non-compliance announcement amounts to about -1.5% for any type of compliance violation, decreases to a stronger -2.8% response for non-compliance where more than one-half of the firm's verified emissions are non-compliant and decreases slightly further to a -3.1% market reaction when all of the firm's verified emissions are involved. Figure 6 also shows that in all cases, CARs over longer windows around the announcement are more negative than those over shorter windows. This fact lends credit to our earlier observation that the impacts of non-compliance are not immediately absorbed by the market and instead take several days to be fully priced.

4.2 Heterogeneity in exposure to carbon price shocks

Having established the value-relevance of non-compliance with regulations of the EU ETS to investors, our next analysis will focus on the sensitivity of the stock returns of regulated firms to shocks in European carbon prices and the extent to which this relationship is moderated by cross-sectional differences in allocation shortfall. To this end, we estimate Equation (7) via panel regression. Most important for our identification strategy is that we include in this regression date fixed effects. This inclusion is crucial in our setting since the date fixed effect subsumes any macroeconomic confounders that simultaneously affect carbon prices and stock returns, such as demand shocks for electricity, sudden increases in industrial production, or recessionary concerns. Since such macro-economic exposure could still be correlated with our main explanatory variable, i.e., allocation shortfall, we also include industry fixed effect into our regression specification to provide further assurance that our estimates are immune to this concern. The inclusion of industry fixed effect allows our inference to be within-industry so that regression estimates β_0 can be interpreted as the additional stock return in response to a 1% shock to European carbon prices for each unit difference of allocation shortfall within an industry. We expect a negative coefficient for β_0, as firms with shortages (surplus) of allowances would be negatively (positively) affected by an increase in carbon prices since they would generally be expected to purchase these allowances at greater cost (sell at greater profits). We optionally include control variables in the estimation of Equation (7) to ensure that our coefficients are not contaminated by the influence of factors deemed important determinants of the cross-section of returns.

Our sample constitutes firms that are headquartered in countries participating in the EU ETS (hereafter referred to as "EU" firms) and firms that are domiciled in countries not participating in the EU ETS (hereafter referred to as "non-EU" firms) but that have operations in participating countries. Particularly, these firms differ in their exposure to the EU ETS. The typical EU firm has 44% of its total emissions regulated by the EU ETS, while the typical non-EU firm has only 13% of emissions regulated. If the ETS affects the stock returns of regulated firms mainly via their profitability, as observed by Bolton, Lam, and Muûls (2023), then these differing exposures should explain variation in sensitivities to carbon price shocks. Hence, to compare the asset-pricing implications of the EU ETS between EU firms and non-EU firms, we estimate Equation (7) separately for panels of EU-headquartered and panels of non-EU headquartered firms.

Table 7 reveals a robust negative interaction effect of allocation shortfall and carbon price shock on regulated firms' stock returns. In other words, stock returns of firms that are short on allocation allowances react more negatively to increases in carbon prices. Our full sample estimates presented in Column 1 of Table 7 point toward an incremental reduction in stock returns equal to 1.42 bps for a one unit larger allocation shortfall in response to a 1% increase in carbon prices for the representative firm in our sample and estimated over all four operational phases of the EU ETS. The inclusion of control variables in Column 2 does not lead our estimates to change meaningfully, suggesting that allocation shortfall is an independent characteristic in comparison to other firm characteristics, and its association with carbon price shocks is not affected by characteristics other than the allocation shortfall.

Columns 3 to 6 in Table 7 estimate the effect separately for firms that are domiciled in participating countries (EU firms) and for firms that are domiciled in non-participating countries (non-EU firms). In both subsamples, we find strong and negative associations between the interactions of allocation shortfalls with carbon prices and stock returns. The estimated coefficients are of similar magnitude, suggesting that both EU and non-EU firms' sensitivity to carbon prices is equally dependent on allocation shortfall. In other words, we find that European and non-European firms hold similar exposures toward European carbon price shocks, suggesting that the profitability impact is not the driving force behind the transmission channel between carbon prices and stock prices. Instead, carbon prices must also affect company valuations via the discount rate, suggesting that investors are taking ETS-related information into account when assessing firms' relative risk exposures.

4.3 Heterogeneity across operational phases

We now turn to investigating how the EU ETS' effect on stock returns varies over the system's four distinct operational phases. Since operational phases imposed widely differing regulatory constraints upon regulated entities and the financial impact of the system gradually increased, it is important to understand how these changing characteristics influence the transmission of carbon prices to stock prices. To do so, we again estimate Equation (7), but now repeat the estimation procedure separately for each operational phase in the EU ETS.

Table 8 corroborates our results. In all phases except for Phase I, a statistically significant negative coefficient is observed on our coefficient of interest, namely the coefficient on the interaction term of allocation shortfall with carbon price changes. The fact that the interaction term is insignificant for the earliest phase of the system (2005 - 2007) might be explained by the generous allocation of allowances during this phase – leading to little variation in the allocation shortfall variable and, therefore, low statistical power in the estimations of the interaction coefficient – and by this phase's low prices so that financial markets likjely did not deem allowance shocks material enough to be reflected in equity valuations. Alternatively, or additionally, it might be that the relative novelty of the carbon pricing mechanism left investors unsure of how to price exposures in the system. In all phases from Phase II to Phase IV, we observe statistically negative interaction coefficients that represent an economically meaningful effect. Surprisingly, we find that the strongest effect of the EU ETS on asset prices occurred in Phase II of the system. This might be caused by the high uncertainty around the system's regulatory features at that time, coupled with the anticipation of more stringent allocation in later phases. Nonetheless, our findings point toward a robust influence of the carbon price on stock prices starting as early as Phase II of the system, even while carbon prices were relatively low and allowances were allocated generously. This finding adds to recent empirical work on the stock market effects of the system during Phase III (Bolton, Lam, and Muûls, 2023;

Millischer, Evdokimova, and Fernandez, 2023; Hengge, Panizza, and Varghese, 2023).

In Table 9, we extend our focus to investigate the different effects within domiciles and across the system's four operational phases. As expected, we do not find any effect of the EU ETS in Phase I on the stock prices of regulated firms when breaking down our analysis to focus on EU and non-EU firms, as reported in Columns 1 and 2 of the table. In nearly all other specifications, we find that the EU ETS' effect on asset prices depends critically on allocation shortfalls. Interestingly and reaffirming our prior conclusions, in Phases II and IV, effects were stronger for non-EU firms than for EU firms. These findings imply that the EU ETS affects the valuation of firms even when these are just marginally exposed to its regulations. This observation challenges the profitability-based explanation of how the EU ETS influences asset prices and lends support to the existence of risk-based explanations. We will explore this potential mechanism further in Section 4.7.

4.4 Asymmetries in exposure to carbon price shocks

In this section, we test for asymmetries in the response of stock prices to carbon price shocks. All our prior specifications tested for a linear effect of allocation shortfall on the carbon price sensitivity, but we are also interested in finding out whether this effect is dominated by a negative return reaction for firms with low allocated allowances in response to increasing carbon prices or by a positive return reaction for firms with high allocated allowances in response to increasing carbon prices. To test for these potential asymmetries, we estimate Equation (8), the outcomes of which are reported in Table 10.

Column 2 of Table 10 provides evidence that over the full sample, the asset-pricing implications of the EU ETS are relatively symmetrically distributed among firms with a large fraction of allocated emissions and firms with a low fraction of allocated emissions. This can be seen by both separate sets of dummy variables being significantly different from zero, with their estimated coefficients having opposing signs of similar magnitude. This symmetry is also present when basing the estimation on EU companies, reported in Columns 3 and 4. However, shifting our focus to non-EU firms, we see that an asymmetry arises. Here, the estimated coefficient on the long coverage $\times$ carbon price shock is positive and significant, while the short coverage interaction does not exhibit a statistically significant effect. This suggests that for the non-EU sample, firms with many allocated allowances mainly benefit from increasing carbon prices but that this does not come at the expense of firms with a low number of allocated allowances.

4.5 Inference from a high-frequency event study

A potential concern in the estimation of our baseline regressions is that the effect of macroeconomic confounders can be correlated with our main treatment variable, allocation shortfall. If this were the case, the effect found in our analysis would arise due to a tendency of firms facing low allocation of shortages compared to verified emissions (a high allocation shortfall) to respond more negatively to macro-economic determinants of both carbon prices and stock returns, such as expectations regarding future industrial production of news reflecting increased likelihood of recessions. This might bias our results to the extent that exposure to macroeconomic shocks is not captured by industry inclusion.

We circumvent any potential confounding effects by adopting Känzig (2023)'s high-frequency identification approach. The central premise of Känzig (2023) is that the change in the carbon price during regulatory announcement is free from such endogeneity concerns since *"... economic conditions are known and priced by the market before the regulatory news, and they are unlikely to change within the tight window ... "* (Känzig, 2023, p. 2). We obtain regulatory events from Känzig (2023) and Hengge, Panizza, and Varghese (2023) and supplement these with our collection for the periods not covered in Känzig (2023) and Hengge, Panizza, and Varghese (2023). We then use a regulatory event indicator as an interaction term in the estimation of Equation (9) to effectively separate the effect of carbon pricing on stock returns for non-regulatory days (which may be influenced by economic confounders) and regulatory event days (which plausibly may be immune to such influence). We include in this estimation fixed effects for country-by-sector-by-year and firms, in line with Hengge, Panizza, and Varghese (2023) and Millischer, Evdokimova, and Fernandez (2023).

Results are reported in Table 11. The first column reports coefficients obtained from regressing returns on allocation shortfalls and the interaction of allocation shortfalls with carbon price changes, which is similar to our baseline specification in Equation (7) except that our baseline estimation includes data fixed effects that control for the potential economic confounders discussed above. Column 1 in Table 11 reports an estimated coefficient on the interaction terms that is positive and highly significant. We can explain this finding in two ways: (i) either firms with high allocation shortfall somehow benefit from increasing carbon prices, which is economically not intuitive and contrary to the main results of our paper, or (ii) the endogeneity concerns discussed in this section and earlier bias the estimation of the interaction term. Next, for completeness, we separately include the interaction between allocation shortfall and the climate policy event, although we do not have prior expectations regarding its sign since the climate policy event includes events that both positively and negatively affect carbon prices and regulatory announcements that do not impact carbon prices cannot be considered surprises (Hengge, Panizza, and Varghese, 2023). Not surprisingly, the estimated coefficient on this interaction term is insignificant from zero. Column 4 reports the most significant specification in this setting. The estimated coefficient of -0.9878 in column 4 of Table 11 suggests that for each unit increase in Allocation Shortfall, the marginal effect of a 1% shock to carbon prices on stock prices *on regulatory event dates* is about -0.99 bps. This point estimate comes very close to our baseline estimation of a -1.43 bps sensitivity to carbon price shocks (in column 2 of Table 7) and therefore suggests that the inclusion of time-fixed effects in our initial specification does a good job at controlling for potential macroeconomic confounders.

4.6 What drives the Carbon Price Sensitivity?

Having established that allocation shortfall crucially determines stocks' exposures towards changes in the EU ETS carbon allowance price, we now turn to investigating the underlying characteristics that drive this relationship. To so do, we adjust Equation (7) to include a triple-interaction term with a firm characteristic C

$$\begin{aligned} \mathrm{r}^{e}_{i,t} = \alpha &+ \beta_0 C_{i,t\text{-}1} \times \mathrm{AS}_{i,t} \times r^{\mathrm{EUA}}_t + \beta_1 \mathrm{AS}_{i,t} \times r^{\mathrm{EUA}}_t + \beta_2 C_{i,t\text{-}1} \times \mathrm{AS}_{i,t} \\ &+ \beta_3 C_{i,t\text{-}1} \times r^{\mathrm{EUA}}_t + \beta_4 \mathrm{AS}_{i,t} + \beta_5 C_{i,t\text{-}1} + \lambda X'_{i,t\text{-}1} + \sigma_{i,t} + \mu_t + \varepsilon_{i,t}, \end{aligned} \tag{11}$$

where $C_{i,t\text{-}1} \times \mathrm{AS}_{i,t} \times r^{\mathrm{EUA}}_t$ captures the triple interaction between the (lagged) firm characteristic, the firm's allocation shortfall, and the change in the carbon price, and all other interaction terms are defined accordingly. Note that the term $\beta_5 C_{i,t\text{-}1}$ is supressed in the cases that C is contained in X. All other terms are defined as in Equation (7). We can interpret β_0 as the additional return response observed for a unit change in the characteristic $C_{i,t}$ in response to a 1%-point change in the carbon price for each unit change in allocation shortfall. Hence, negative coefficient estimates of β_0 correspond to characteristics $C_{i,t}$ that lead to larger sensitivities to carbon price shocks.

We test this relationship for six characteristics C: emissions intensity (combined scope 1&2 emissions scaled by revenues), EU ETS exposure (verified emissions regulated by the EU ETS scaled by total scope 1 emissions), the lagged carbon price (as of end-of-December in year t-1, firm size (lagged log of market capitalization), profitability (lagged return on equity), and leverage (lagged debt scaled by lagged assets). The first three characteristics proxy for specifics of the system coupled with firm's carbon risk exposures. We expect that the carbon price sensitivity is stronger for firms with higher carbon emissions intensity, since they are more exposed to emissions regulation. We also expect this relationship to be stronger when the carbon price is higher, since the system's implications are more material at higher carbon prices. We further expect that the extent to which firms are exposed to the system, as measured by the fraction of emissions covered under the EU ETS to total scope 1 emissions, should also mediate the effect. The next three characteristics proxy for a firm's tolerance to risk. Larger firms tend to be more diversified and have greater lobbying power, which leaves them less affected by carbon price shocks. Firms that are more profitable and less leveraged are better able to withstand increases to both costs and risks, regardless of wether these increases are due to the EU ETS or due to other reasons. Hence, we would expect a positive β_0 for firm size and profitability, and a negative coefficient for financial leverage.

Table 12 reports the results. Firms with higher emission intensities exhibit stronger return responses to changes in the carbon price, as the estimated coefficient in the first column indicates. We observe a similar finding for higher carbon prices. The extent to which a firm is regulated by the system, as measure by the EU ETS exposure, does not lead to a statistically significant reduction in carbon price exposure. This finding is in line with our earlier observation that both international and European firms exhibit similar return reactions to carbon price changes. We also do not observe a significant interaction effect with firm size and profitibability. However, financial leverage does seem to play a role, as firms with higher debt levels relative to the value of their assets are more negatively (positively) affected by increases to carbon prices when their allocation shortfall is large (small).

4.7 Cash-flow versus disount-rate-based explanations

We now turn to further investigating the cash-flow-based versus discount rate-based channels through which the EU ETS is affecting stock prices. We do so by investigating 1-year ahead changes to the implied cost of capital and return on equity our baseline using our baseline regression specification. Note that we conduct this analysis on a monthly panel, since observations on ICCs and ROEs are sparsely available and only evolve at the monthly and quarterly frequency. For the findings observed in our prior analysis to hold, we expect ex-ante that increases in the carbon price positively (negatively) affect the cost of capital (profitability). In other words, we expect a positive coefficient on the Allocation Shortfall $\times r^{\text{EUA}}$ interaction term for the specification with ΔICC as the response variable, and a negative coefficient on the interaction term with ΔROE as the response variable.

Table 13 tabulates the output from this regression. For our overall sample, one can see that firms with higher allocation shortfalls experience both an increase in the cost of capital and a reduction in profitability in the year following an increase in the carbon price. These effects are statistically significant. For the specification with increases in cost of capital as the response, the variable of interest is only marginally significant at a 10% level. There are at least two reasons why we observe a lower statistical significance in comparison to our baseline return effects. First, the number of observations is much smaller in our monthly panel compared to our baseline estimates, which are based on daily observations. Second, the estimations of ICCs are notoriously noisy, thereby reducing the precision of our estimates.

The results in Table 13 are further seperated for the European and non-European samples. The third and fourth columns show that among the EU-headquartered firms, the carbon price sensitivity is driven primarily via the cash-flow channel. That is, these firms' returns are low in periods of increasing carbon prices mainly because their profitability is affected in the year after. Note that this effect holds for the interaction term, but also for the coefficient directly estimated on the allocation shortfall. In other words, EU firms with higher allocation shortfalls tend to be riskier and less profitable, the latter especially so in periods following increases in the carbon price. For firms headquartered outside of the European Union, the effect spills through via the discount rate channel, as columns 5 and 6 show. This implies that following increases in the carbon price, non-EU firms with higher allocation shortfalls experience low returns due to increasing discount rates.

5 Conclusion

We study how carbon prices affect stock prices of regulated entities over all four operational phases of the EU ETS. Our empirical strategy includes the release of important information in the EU ETS, changes in carbon prices and cross-sectional variation in the ratio of allocated allowances versus verified emissions, and a high-frequency identification approach as in Känzig (2023) to rule out any potential confounding effects. We show that stock prices respond strongly and negatively to the release of information regarding non-compliance with the EU ETS' regulations. Our findings further point toward a statistically significant effect of carbon prices on stock prices starting from Phase II of the EU ETS that primarily depends on the shortage of freely allocated allowances in relation to verified emissions. The transmission of carbon prices to stock prices is not limited to European firms that are relatively heavily regulated by the system but also applies to non-European firms that are regulated to a much lesser extent. Our findings complement recent observations by for example Bolton, Lam, and Muûls (2023) that carbon pricing affects company valuations via their profitability channel, and lends support to an additional interpretation that is risk-based. We subject this relationship to a variety of robustness tests and find that in holds across various specifications, geographic regions, time periods and diferent empirical approaches.

The contribution of our paper is twofold. First, our paper sheds further light on the transmission of information in the carbon market to stock prices. We show that in particular information about the failure to comply with the system's regulations leads to pronounced and negative stock market effects. As our sample periods spans the full operational history of the EU ETS, we also compare how institutional changes to the system as well as variation in carbon prices affect return responses to carbon price increases. Second, we lay out an elaborate data construction procedure that matches installation level data from the EUTL to historically representative parent companies which allows for a precise aggregation of allocated allowances and verified emissions at the firm level.

Our findings hold several implications for policymakers. First, our analysis shows that information regarding compliance with the carbon markets is rapidly incorporated by financial markets. Such information can be used as a replacement or addition to emissions data provided by commercial vendors. Second, we show that informational spillovers from the carbon market to the stock market can already form at relatively low carbon prices and lenient allocation policies, and for firms that have only limited exposure to the system via only their foreign operations. Third, the impact of the EU ETS on financial stability seems negligible up to this point, as evidenced by the relatively limited economic significance of our estimates. Lastly, we show that carbon prices can affect firms' cost of capital, constituting a neccessary condition for carbon pricing to lead to increased green investments.

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Figures and Tables

Figures

Figure 1: Total Emissions Regulated by the EU ETS for Firms in Sample
This figure shows the total number of verified emissions and allocated allowances for the firms covered in our sample.

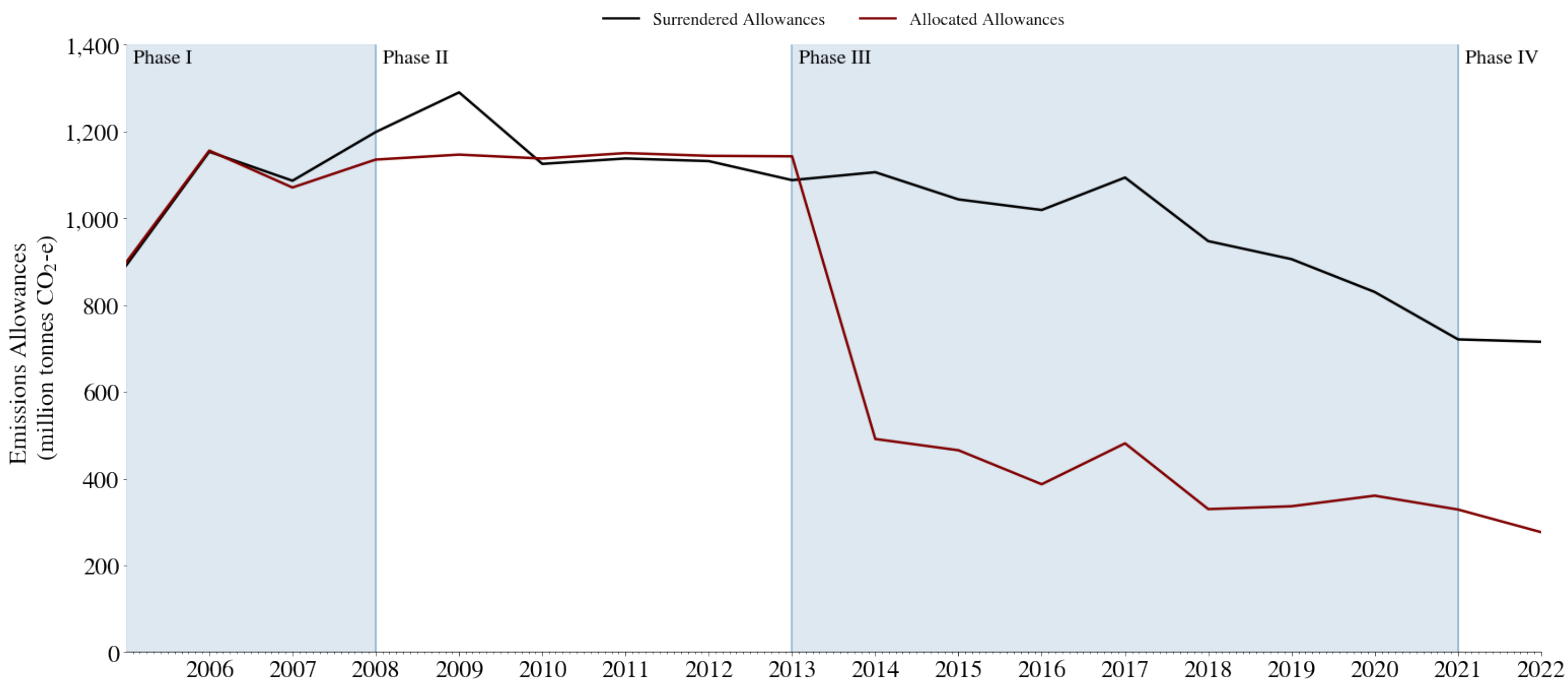


Figure 2: Price of EU Emissions Allowances

This figure shows the daily settlement prices of the ICE ECX front futures contract over the period from April 2005 to August 2023. We use the ICE ECX front future as our default EU emissions allowance price. The data have been obtained from FactSet, where the series is available under FactSetID `ECF-FDS`.

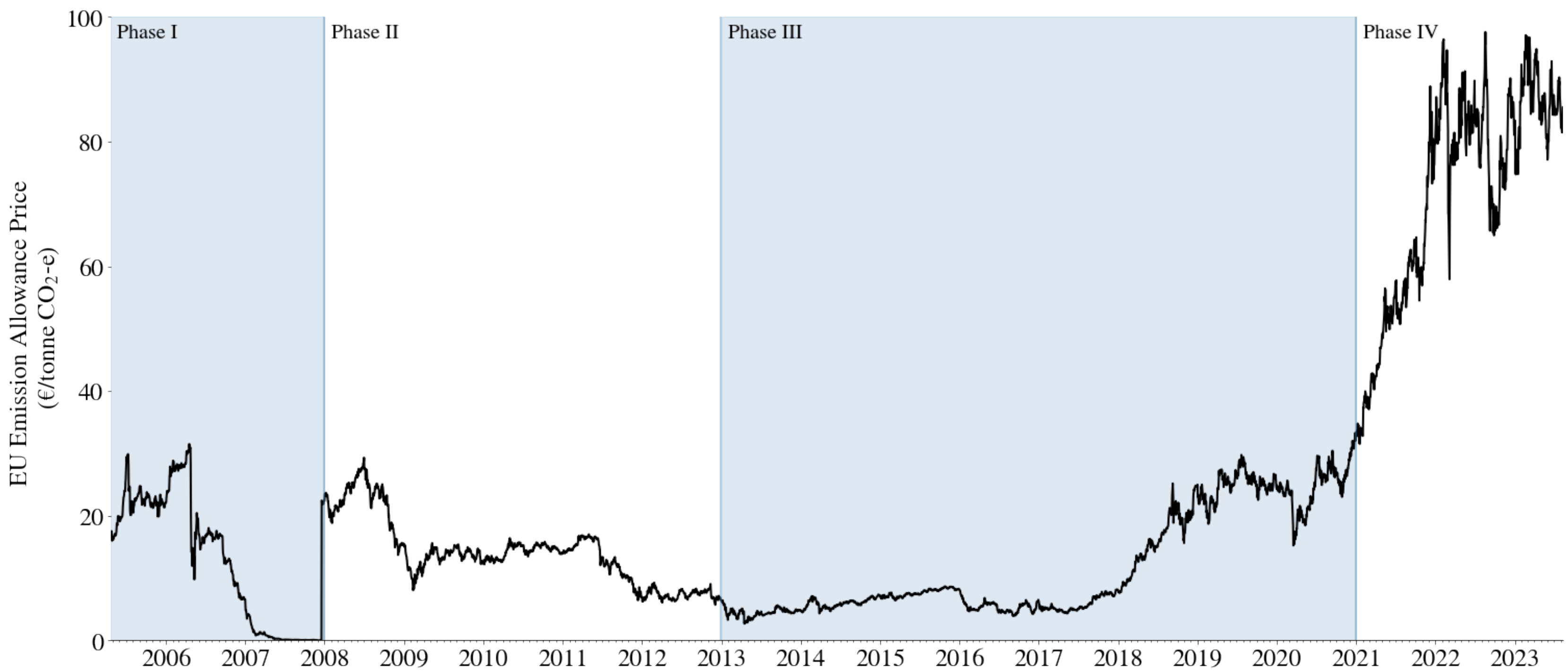


FIGURE 3: Känzig (2023) Carbon Policy Surprises

This figure shows the Känzig (2023) Carbon Policy Surprise index. The Carbon Policy Surprise is defined as in Equation (1) as the daily return on the EUA futures on an EU ETS regulatory event date and zero otherwise. Regulatory event dates are dates on which the European Commission announces a regulatory update to the EU ETS and are presented in detail in Table A4. Regulatory events occurring in Phase II up to and before November 11, 2019, were collected by Känzig (2023) and are reported in Table A.1 of Känzig (2023). Events occurring between December 12, 2019, and May 31, 2021, were collected by Hengge, Panizza, and Varghese (2023) and are reported in Table A.2 of Hengge, Panizza, and Varghese (2023). Events occurring after June 29, 2021, were collected by the authors from press releases obtained via `https://ec.europa.eu/clima/news/news_archives_en`.

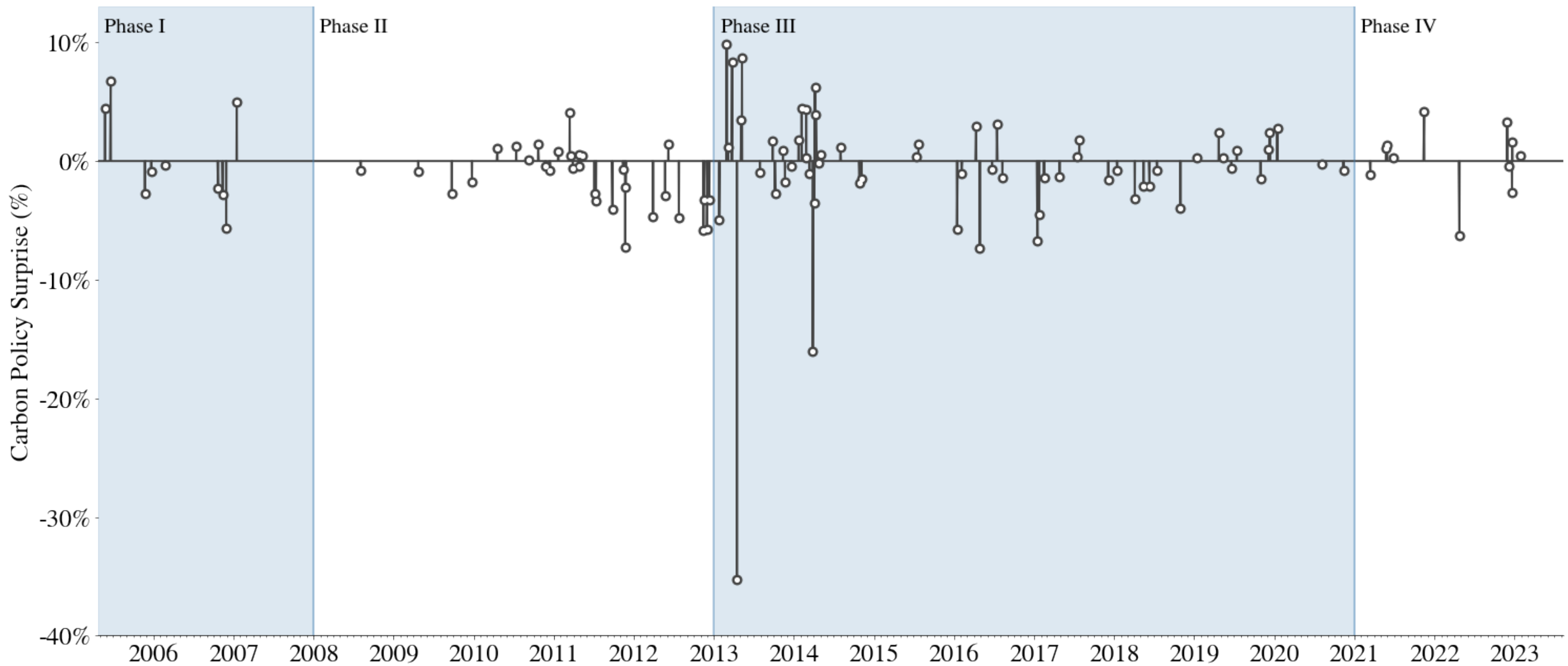


Figure 4: Effect of EU ETS Non-Compliance
This figure shows estimated cumulative abnormal returns (CARs) around the announcement date for firms that are non-compliant with the EU ETS regulations. We deem firms non-compliant if they own at least one installation that fails to surrender allowances equal to verified emissions by April 30^{th} of the year following the compliance year. The coefficients were estimated using Equation (6). The shaded area plots a 95% confidence interval around the point estimates based on standard errors clustered at the firm level. Abnormal returns are calculated for the CAPM model. Figure A2 in the Appendix additionally reports results concerning the Carhart (1997) 4-factor model and for the Fama and French (2015) 5-factor model augmented by the Carhart (1997) momentum factor. We explore CARs to stronger definitions of non-compliance in Figure 6 below.

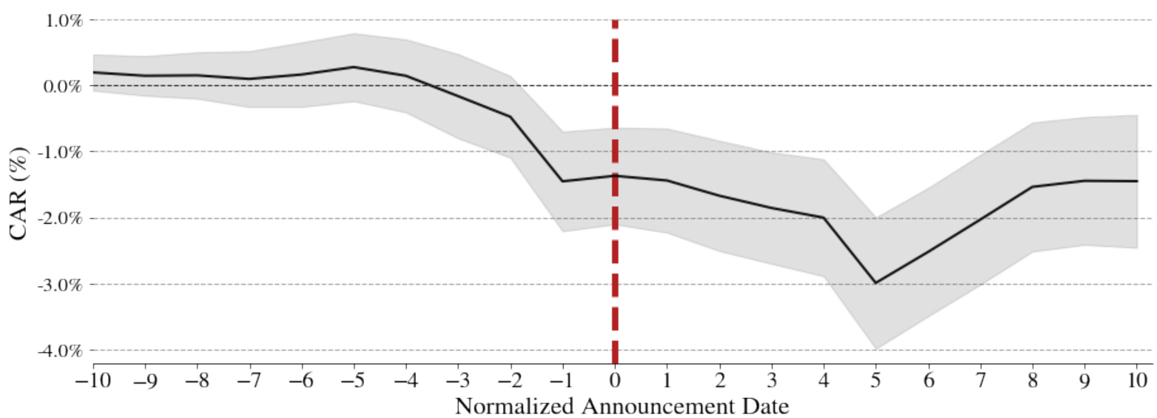


Figure 5: Effect of EU ETS Non-Compliance: First-Time vs. Repeat Offenders
This figure shows estimated cumulative abnormal returns (CARs) around the announcement date for firms that are first-time versus repeatedly non-compliant with the EU ETS' regulations. We deem firms non-compliant if they own at least one installation that fails to surrender allowances equal to verified emissions by April 30th of the year following the compliance year. Up to year t, first-time offenders have a flawless compliance history while repeated offenders have been non-compliant at least once in their history. The coefficients were estimated using Equation (6). The shaded area plots a 95% confidence interval around the point estimates based on standard errors clustered at the firm level. Abnormal returns are calculated for the CAPM model. Figure A2 in the Appendix additionally reports results for the Carhart (1997) 4-factor model and for the Fama and French (2015) 5-factor model augmented by the Carhart (1997) momentum factor. We explore CARs to stronger definitions of non-compliance in Figure 6 below.

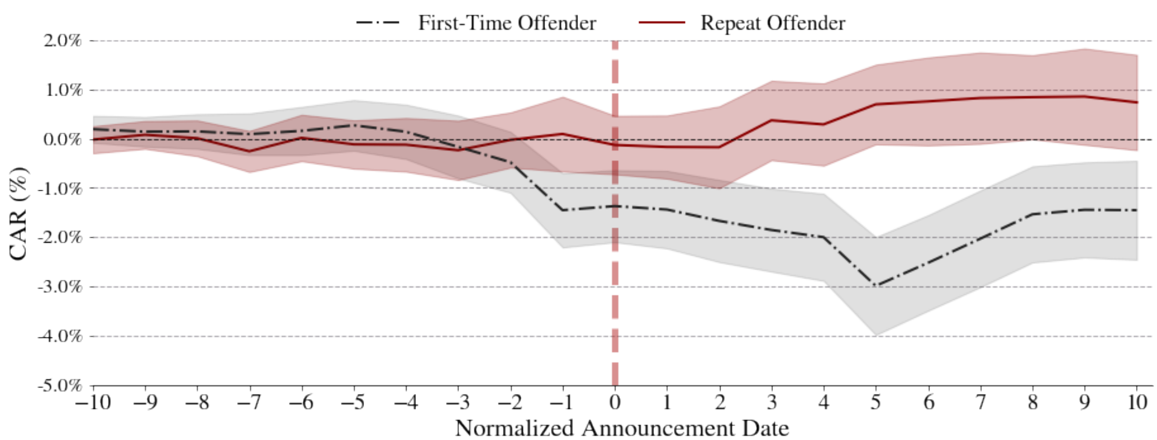
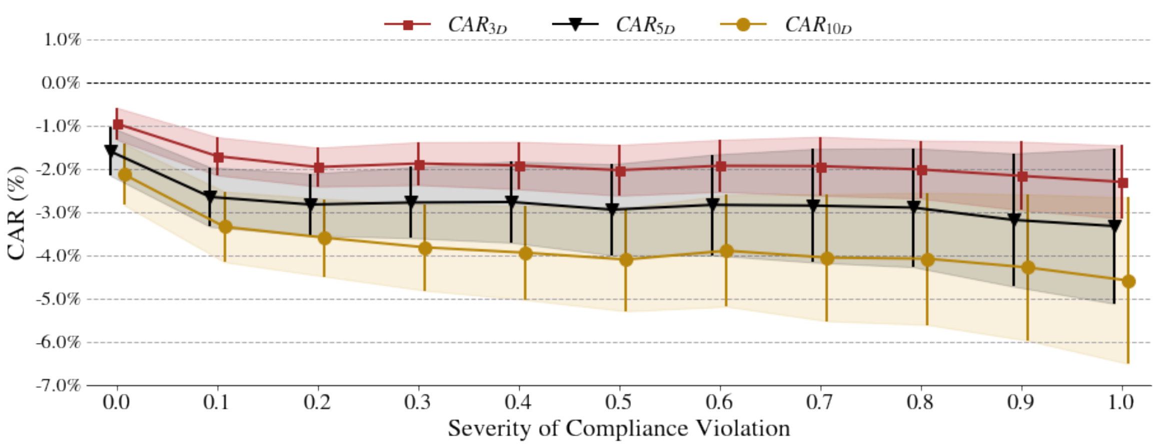


Figure 6: Effect of EU ETS Non-Compliance: Severity of Compliance Violation
This figure shows average cumulative abnormal returns for 3-day, 5-day, and 10-day windows around the announcement date (respectively CAR_{3D}, CAR_{5D}, and CAR_{10D}) for increasingly severe compliance violations q. We deem firms non-compliant if they own at least one installation representing at least $100 \times q\%$ of the firm's total verified emissions that fails to surrender allowances equal to verified emissions by April 30^{th} of the year following the compliance year. This threshold q spans the interval $(0, 1]$ in iterations of size 0.1. Our baseline estimates in Figure 4 make use of a threshold value $q > 0\%$. All CARs are calculated with respect to the CAPM model. All results are based on regressions including industry fixed effects. Vertical bars and shaded areas indicate 95% confidence intervals around the point estimates.



Tables

Table 1: Number of Firms in Sample by Year
This table reports the number of firms in our sample by year.

Year	N.o. Firms in Sample	Year	N.o. Firms in Sample
2005	533	2015	709
2006	568	2016	668
2007	612	2017	667
2008	657	2018	657
2009	668	2019	656
2010	664	2020	670
2011	645	2021	604
2012	646	2022	581
2013	692	2023	557
2014	695		

Table 2: Number of Firms in Sample by Headquarter Country

This table reports the number of firms in our sample by their headquarters' country. Information on headquarters is obtained from Refinitiv Eikon. Norway joined the EU ETS in 2008. Switzerland joined the EU ETS in 2020. The United Kingdom exited the EU ETS in 2021.

Country	N.o. Firms in Sample	Country	N.o. Firms in Sample
AUSTRALIA	6	LUXEMBOURG	5
AUSTRIA	15	MALAYSIA	8
BELGIUM	20	MEXICO	4
BERMUDA	2	MONACO	1
BRAZIL	5	NETHERLANDS	19
BULGARIA	7	NORWAY	11
CANADA	14	POLAND	26
CHINA	9	PORTUGAL	5
CROATIA	4	ROMANIA	2
CZECH REPUBLIC	1	RUSSIA	7
DENMARK	7	SAUDI ARABIA	3
FINLAND	13	SINGAPORE	2
FRANCE	51	SLOVAK REPUBLIC	1
GERMANY	50	SLOVENIA	4
GREECE	5	SOUTH AFRICA	4
HONG KONG	3	SPAIN	26
HUNGARY	4	SWEDEN	24
INDIA	17	SWITZERLAND	15
IRELAND	10	TAIWAN	1
ISRAEL	4	THAILAND	3
ITALY	30	TURKEY	3
JAPAN	53	UNITED ARAB EMIRATES	1
KOREA	9	UNITED KINGDOM	67
LATVIA	1	UNITED STATES OF AMERICA	123
LITHUANIA	4		

Table 3: Allocation by Industry and Phase: Absolute Emissions and Allowances

This table reports total regulated emissions and allocated allowances in millions of tonnes of CO_2-equivalent by GICS industry sectors and ETS phase for the firms in our sample. The two columns under "All Phases" report combined numbers for all phases of the EU ETS (2005 - 2023), while the other columns to the right report numbers individually for Phase I (2005 - 2007), Phase II (2008 - 2012), Phase III (2013 - 2020), and Phase IV (2021 - 2030). The "Other" industry category encompasses the GICS sectors "Information Technology", "Communication Services", and "Real Estate" as these sectors are relatively uncommon in our sample.

		All Phases		Phase I		Phase II		Phase III		Phase IV	
Industry	Firms	Emissions	Allocations	Emissions	Allocations	Emissions	Allocations	Emissions	Allocations	Emissions	Allocations
Energy	44	1,906.58	1,607.84	105.14	110.33	578.32	598.43	936.45	733.46	286.68	165.63
Materials	197	3,839.74	4,089.93	177.16	205.69	950.12	1,173.46	1,974.29	2,034.80	738.17	675.97
Industrials	126	353.91	347.23	27.49	27.98	125.17	138.82	154.61	155.32	46.65	25.11
Cons. Discr.	56	79.17	66.83	3.65	4.26	19.26	24.19	37.93	30.72	18.33	7.65
Cons. Staples	66	62.00	55.10	2.25	2.63	17.39	20.78	32.11	25.80	10.26	5.89
Health Care	33	40.01	38.11	2.73	3.18	15.66	16.72	18.25	16.03	3.38	2.19
Financials	48	106.17	109.57	43.32	53.05	15.83	18.33	36.63	30.45	10.40	7.75
Utilities	56	10,100.07	5,224.14	614.43	568.72	3,491.80	2,995.00	4,912.31	1,615.98	1,081.52	44.44
Other	33	6.58	8.15	0.57	0.88	2.10	3.30	3.01	3.37	0.89	0.60

Table 4: Allocation by Industry and Phase: Relative Emissions and Allowances

This table reports relative regulated emissions and allocated allowances compared to total regulated emissions and allowances by GICS industry sectors and ETS phase for the firms in our sample. The two columns under "All Phases" report combined numbers for all phases of the EU ETS (2005 - 2023), while the other columns to the right report numbers individually for Phase I (2005 - 2007), Phase II (2008 - 2012), Phase III (2013 - 2020), and Phase IV (2021 - 2030). The "Other" industry category encompasses the GICS sectors "Information Technology", "Communication Services", and "Real Estate" as these sectors are relatively uncommon in our sample.

		All Phases		Phase I		Phase II		Phase III		Phase IV	
Industry	Firms	Emissions	Allocations	Emissions	Allocations	Emissions	Allocations	Emissions	Allocations	Emissions	Allocations
Energy	44	11.56%	13.92%	10.76%	11.30%	11.09%	11.99%	11.55%	15.79%	13.05%	17.71%
Materials	197	23.28%	35.42%	18.14%	21.06%	18.22%	23.52%	24.36%	43.80%	33.61%	72.28%
Industrials	126	2.15%	3.01%	2.81%	2.86%	2.40%	2.78%	1.91%	3.34%	2.12%	2.68%
Cons. Discr.	56	0.48%	0.58%	0.37%	0.44%	0.37%	0.48%	0.47%	0.66%	0.83%	0.82%
Cons. Staples	66	0.38%	0.48%	0.23%	0.27%	0.33%	0.42%	0.40%	0.56%	0.47%	0.63%
Health Care	33	0.24%	0.33%	0.28%	0.33%	0.30%	0.34%	0.23%	0.34%	0.15%	0.23%
Financials	48	0.64%	0.95%	4.44%	5.43%	0.30%	0.37%	0.45%	0.66%	0.47%	0.83%
Utilities	56	61.23%	45.24%	62.91%	58.23%	66.95%	60.03%	60.60%	34.78%	49.24%	4.75%
Other	33	0.04%	0.07%	0.06%	0.09%	0.04%	0.07%	0.04%	0.07%	0.04%	0.06%

TABLE 5: Top 20 Firms in Sample by Verified Emissions in 2022

This table reports the 20 listed firms that have the highest verified emissions under the EU ETS in 2022. Verified emissions and allocated allowances are reported in millions of tonnes of CO_2-equivalent. The table further reports on the firm's headquarters country, the fraction of emissions not covered by allocated allowances ("Allocation Shortfall"), and the monetary value of this shortfall in millions of euros, as per end-of-2021 allowance prices.

Company	Country	Verified Emissions (10^6 tonnes CO_2-e)	Allocated Allowances (10^6 tonnes CO_2-e)	Allocation Shortfall (%)	Allocation Shortfall (€ millions)
PGE POLSKA GRUPA ENERGETYCZNA SA	POLAND	70.18	0.62	99.12%	5,573
RWE AG	GERMANY	64.78	0.85	98.69%	5,122
ARCELORMITTAL SA	LUXEMBOURG	61.31	55.03	10.24%	503
THYSSENKRUPP AG	GERMANY	25.40	22.20	12.60%	256
ENEA SA	POLAND	22.29	0.15	99.33%	1,774
ENGIE SA	FRANCE	22.15	0.55	97.50%	1,730
CEZ AS	CZECH REPUBLIC	21.62	0.35	98.40%	1,704
ENI SPA	ITALY	21.49	7.88	63.31%	1,090
HEIDELBERG MATERIALS AG	GERMANY	21.36	18.42	13.75%	235
ENEL SPA	ITALY	20.48	0.02	99.92%	1,639
FORTUM OYJ	FINLAND	18.38	0.75	95.92%	1,412
TOTALENERGIES SE	FRANCE	17.02	11.21	34.12%	465
ORLEN SA	POLAND	16.57	7.56	54.37%	722
ELECTRICITE DE FRANCE SA	FRANCE	15.31	0.28	98.14%	1,203
PUBLIC POWER CORPORATION SA	GREECE	13.83	0.02	99.83%	1,106
CRH PLC	IRELAND	13.48	10.46	22.37%	242
VOESTALPINE AG	AUSTRIA	12.96	9.10	29.82%	310
TAURON POLSKA ENERGIA SA	POLAND	12.45	0.16	98.71%	984
BASF SE	GERMANY	12.00	9.19	23.37%	225
ENBW ENERGIE BADEN WUERTTEMBERG AG	GERMANY	11.45	0.19	98.33%	902

Table 6: Descriptive Statistics

The table reports descriptive statistics on the variables used in our analysis. All variables are defined as in Table A1. Panel A reports daily returns, daily return volatilities, and monthly market capitalizations obtained from Refinitiv Eikon. Panel B reports emissions variables obtained from the EU Transaction Log and S&P's Trucost. Allowance Shortfall is the percentage difference between the emission allowances allocated scaled by the verified emissions. A higher value indicates a larger shortfall. The Carbon Tax Rate (CTR) is the monetary value of the allocation shortfall scaled by the company's market capitalization. Panel C reports on the lagged month-end characteristics of the firms included in our sample obtained from Refinitiv Eikon. Our sample period spans the inception of the EU ETS in 2005 to the, as of writing, latest completed compliance year 2023.

				Percentiles						
	N. Obs.	Mean	SD	1%	5%	25%	Median	75%	95%	99%
Panel A: Market variables										
Excess Return* (%)	2,791,950	0.041	2.445	-6.717	-3.447	-0.993	0.000	1.027	3.593	7.288
Return Volatility (%)	2,791,950	2.187	1.037	0.807	1.045	1.494	1.951	2.602	4.154	5.842
Market Capitalization (millions €)	2,031,680	17,489	52,923	11	81	991	4,039	15,536	72,976	190,521
β_{Market}	2,584,865	0.599	0.382	-0.166	0.045	0.335	0.565	0.833	1.275	1.615
β_{Size}	2,584,865	-0.023	0.719	-1.603	-1.134	-0.492	-0.055	0.406	1.203	1.907
β_{Value}	2,584,865	0.138	0.703	-1.524	-0.927	-0.263	0.095	0.500	1.328	2.215
$\beta_{Momentum}$	2,584,865	0.018	0.575	-1.497	-0.883	-0.278	0.009	0.302	0.938	1.645
Panel B: EU ETS & Emission variables										
Verified Emissions (in millions of tonnes CO2-e)	2,509,211	1.827	8.284	0.000	0.000	0.011	0.050	0.364	8.071	39.441
Allocated Allowances (in millions of tonnes CO2-e)	2,509,211	1.293	6.304	0.000	0.000	0.010	0.047	0.298	5.389	25.573
Total Emissions (in millions of tonnes CO2-e)	1,837,567	7.349	17.140	0.007	0.043	0.316	1.179	5.127	39.785	87.440
Allocation Shortfall (%)	2,429,350	19.553	29.301	0.000	0.000	0.000	0.000	30.412	93.234	100.000
Carbon Tax Rate (% of Mkt. Cap.)	1,850,303	0.205	1.275	-1.733	-0.297	-0.006	0.000	0.011	1.004	10.143
Panel C: Firm characteristics										
Return on Equity* (%)	1,851,839	14.686	18.777	-54.025	-5.230	6.889	12.390	19.914	43.390	105.923
Return on Assets* (%)	2,070,137	4.051	5.880	-18.053	-5.132	1.373	3.828	6.750	13.623	23.117
Book to Market*	2,066,612	0.881	0.888	-0.094	0.138	0.371	0.637	1.060	2.477	5.511
Leverage* (%)	2,069,979	27.889	15.001	0.071	4.187	17.143	26.605	37.083	56.141	68.921
PP&E to Assets* (%)	1,973,871	0.711	0.412	0.016	0.127	0.369	0.687	0.993	1.437	1.876
Investment to Assets*	1,906,343	0.078	0.132	0.000	0.001	0.011	0.034	0.087	0.282	0.809

*Winsorised at the 1%-level.

Table 7: Allocation Shortfall and Carbon Price Sensitivity

This table reports results from estimating Equation (7). Variables are defined in Table A1. The sample period starts in 2005 and ends in 2023. Standard errors are two-way clustered at the firm and date level. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	*Excess Return*					
	(1)	(2)	(3)	(4)	(5)	(6)
Allocation Shortfall $\times$ r^{EUA}	-1.4251***	-1.4280***	-1.8956***	-1.9051***	-1.8687***	-1.8620***
	(-3.336)	(-3.342)	(-3.966)	(-3.984)	(-3.824)	(-3.810)
Allocation Shortfall	0.0130	0.0131	0.0107	0.0111	0.0236*	0.0239*
	(1.337)	(1.337)	(0.890)	(0.925)	(1.771)	(1.802)
ln(Market Cap.)	-	-0.0004	-	0.0006	-	-0.0060**
	-	(-0.230)	-	(0.259)	-	(-2.242)
Return on Equity	-	0.0003**	-	0.0004**	-	0.0001
	-	(2.144)	-	(2.117)	-	(0.700)
PP&E to Assets	-	0.0152**	-	0.0213***	-	0.0008
	-	(2.254)	-	(2.877)	-	(0.068)
Investment to Assets	-	-0.0303	-	-0.0417	-	-0.0107
	-	(-1.336)	-	(-1.602)	-	(-0.271)
Book to Market	-	0.0132***	-	0.0173***	-	0.0041
	-	(2.646)	-	(3.152)	-	(0.456)
Leverage	-	0.0072	-	-0.0016	-	0.0040
	-	(0.428)	-	(-0.074)	-	(0.174)
Market Beta	-	0.0231	-	0.0189	-	0.0501
	-	(1.029)	-	(0.830)	-	(1.525)
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Domicile	All	All	EU	EU	Non-EU	Non-EU
N.o. Obs.	1,387,475	1,387,475	878,033	878,033	509,442	509,442
R^2-Adj.	0.213	0.213	0.258	0.258	0.198	0.199

TABLE 8: Allocation Shortfall and Carbon Price Sensitivity by Phase

This table reports results from estimating Equation 7. Variables are defined in Table A1. The sample period starts in 2005 and ends in 2023. Standard errors are two-way clustered at the firm and date level. Phase I of the EU ETS ran from 2005 to 2007, Phase II from 2008 to 2012, Phase III from 2013 to 2020, and Phase IV from 2021 to 2030. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	*Excess Returns*			
	(1)	(2)	(3)	(4)
Allocation Shortfall × r^{EUA}	0.8396	-3.7414***	-1.0863**	-1.9932*
	(1.348)	(-3.964)	(-1.989)	(-1.831)
Allocation Shortfall	0.0112	0.0102	0.0048	0.0282
	(0.300)	(0.439)	(0.404)	(1.552)
ln(Market Cap.)	-0.0067	-0.0024	0.0007	0.0016
	(-1.279)	(-0.579)	(0.279)	(0.392)
Return on Equity	0.0008*	0.0004	0.0004**	-0.0002
	(1.696)	(1.191)	(2.107)	(-0.628)
PP&E to Assets	-0.0416**	0.0305**	0.0131	0.0190
	(-2.334)	(2.082)	(1.440)	(1.201)
Investment to Assets	-0.0236	-0.0709	-0.0168	0.0049
	(-0.356)	(-1.280)	(-0.594)	(0.095)
Book to Market	-0.0194	0.0114	0.0147**	0.0184
	(-1.525)	(1.178)	(2.194)	(1.442)
Leverage	-0.0184	-0.0438	0.0311	0.0103
	(-0.377)	(-1.386)	(1.320)	(0.228)
Market Beta	-0.0141	0.0460	0.0232	0.0036
	(-0.245)	(0.881)	(0.760)	(0.067)
Date FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Phase	Phase I	Phase II	Phase III	Phase IV
N.o. Obs.	107,607	375,727	693,133	211,008
R^2-Adj.	0.188	0.260	0.191	0.166

Table 9: Allocation Shortfall and Carbon Price Sensitivity by Phase and Domicile

This table reports results from estimating Equation (7) separately for each phase of the EU ETS and for companies that are headquartered in the EU (including non-EU countries that participate in the EU ETS) and non-EU countries that do not participate in the EU ETS. Variables are defined in Table A1 in the Appendix. The sample period starts in 2005 and ends in 2023. Standard errors are two-way clustered at the firm and date level. Phase I of the EU ETS ran from 2005 to 2007, Phase II from 2008 to 2012, Phase III from 2013 to 2020, and Phase IV from 2021 to 2030. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	*Excess Return*							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Allocation Shortfall × r^{EUA}	0.6986	1.5360	-2.8272***	-5.7651***	-1.7936***	-1.6123	-2.7264**	-3.5193***
	(0.877)	(0.814)	(-2.935)	(-3.545)	(-2.963)	(-1.294)	(-2.158)	(-3.366)
Allocation Shortfall	0.0268	-0.0251	0.0053	0.0210	-0.0010	0.0212	0.0195	0.0475*
	(0.610)	(-0.363)	(0.210)	(0.437)	(-0.065)	(1.257)	(0.834)	(1.742)
ln(Market Cap.)	-0.0059	-0.0194**	0.0025	-0.0108*	0.0017	-0.0041	-0.0035	0.0048
	(-0.929)	(-2.005)	(0.497)	(-1.770)	(0.517)	(-1.125)	(-0.628)	(0.892)
Return on Equity	0.0008	0.0007	0.0007	-0.0001	0.0005*	0.0002	-0.0005	-0.0002
	(1.415)	(0.861)	(1.547)	(-0.162)	(1.777)	(0.924)	(-0.902)	(-0.412)
PP&E to Assets	-0.0334*	-0.0877*	0.0465***	-0.0006	0.0151	0.0070	0.0168	0.0153
	(-1.731)	(-1.726)	(3.147)	(-0.016)	(1.525)	(0.437)	(0.789)	(0.754)
Investment to Assets	-0.0086	-0.0960	-0.0756	-0.0754	-0.0223	-0.0120	-0.0848	0.1356*
	(-0.148)	(-0.575)	(-1.353)	(-0.612)	(-0.593)	(-0.287)	(-1.364)	(1.693)
Book to Market	-0.0131	-0.0327	0.0197*	-0.0019	0.0196***	0.0019	0.0164	0.0281*
	(-1.087)	(-0.635)	(1.852)	(-0.099)	(2.704)	(0.156)	(1.033)	(1.656)
Leverage	-0.0024	-0.0295	-0.0571	-0.0537	0.0252	0.0279	0.0240	-0.0263
	(-0.039)	(-0.394)	(-1.418)	(-1.023)	(0.854)	(0.929)	(0.440)	(-0.495)
Market Beta	0.0146	-0.0675	0.0319	0.0884	0.0114	0.0584	0.0059	0.0332
	(0.249)	(-0.854)	(0.577)	(1.297)	(0.383)	(1.184)	(0.107)	(0.496)
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Phase	Phase I	Phase I	Phase II	Phase II	Phase III	Phase III	Phase IV	Phase IV
Domicile	EU	Non-EU	EU	Non-EU	EU	Non-EU	EU	Non-EU
N.o. Obs.	74,429	33,178	252,435	123,292	431,192	261,941	119,977	91,031
R^2-Adj.	0.250	0.145	0.311	0.236	0.224	0.191	0.218	0.153

Table 10: Allowance Allocation and Carbon Price Sensitivity

This table reports results from estimating Equation (7). Variables are defined in Table A1. The sample period starts in 2005 and ends in 2023. Standard errors are two-way clustered at the firm and date level. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	*Excess Return*					
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}_{\text{Short Allocation}} \times r^{\text{EUA}}$	-0.3382*	-0.3389*	-0.5859**	-0.5875**	-0.2730	-0.2699
	(-1.939)	(-1.942)	(-2.542)	(-2.546)	(-1.022)	(-1.010)
$\mathbb{1}_{\text{Short Allocation}}$	0.0035	0.0039	0.0042	0.0051	0.0027	0.0012
	(0.710)	(0.790)	(0.688)	(0.821)	(0.341)	(0.154)
$\mathbb{1}_{\text{Long Allocation}} \times r^{\text{EUA}}$	0.4190***	0.4199***	0.5081***	0.5096***	0.3702*	0.3682*
	(2.748)	(2.752)	(2.710)	(2.715)	(1.675)	(1.665)
$\mathbb{1}_{\text{Long Allocation}}$	-0.0000	-0.0006	0.0045	0.0032	-0.0077	-0.0080
	(-0.008)	(-0.144)	(0.858)	(0.622)	(-1.150)	(-1.205)
ln(Market Cap.)	-	-0.0009	-	0.0005	-	-0.0073***
	-	(-0.484)	-	(0.205)	-	(-2.780)
Return on Equity	-	0.0003**	-	0.0004**	-	0.0001
	-	(1.982)	-	(2.113)	-	(0.418)
PP&E to Assets	-	0.0164**	-	0.0241***	-	-0.0007
	-	(2.470)	-	(3.340)	-	(-0.055)
Investment to Assets	-	-0.0319	-	-0.0392	-	-0.0196
	-	(-1.458)	-	(-1.551)	-	(-0.524)
Book to Market	-	0.0110**	-	0.0143***	-	0.0040
	-	(2.274)	-	(2.792)	-	(0.467)
Leverage	-	0.0056	-	-0.0072	-	0.0036
	-	(0.337)	-	(-0.354)	-	(0.158)
Market Beta	-	0.0237	-	0.0193	-	0.0517
	-	(1.052)	-	(0.856)	-	(1.559)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Regions	All	All	EU	EU	Non-EU	Non-EU
N.o. Obs.	1,480,101	1,480,101	925,068	925,068	555,033	555,033
R^2-Adj.	0.208	0.208	0.254	0.254	0.193	0.193

TABLE 11: High Frequency Event Study Around Climate Policy Events

This table reports results from estimating Equation (7) based on Känzig (2023)'s high-frequency identification approach. Variables are defined in Table A1. The sample period starts in 2005 and ends in 2023. Standard errors are two-way clustered at the firm and date level. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	*Excess Return*			
	(1)	(2)	(3)	(4)
Allocation Shortfall	-0.1811	-0.0561	-0.1174	-0.2019
	(-1.037)	(-0.314)	(-0.358)	(-1.147)
Allocation Shortfall × r^{EUA}	1.1556***	-	-	1.1836***
	(8.589)	-	-	(8.597)
Allocation Shortfall × Climate Policy Event	-	-0.0190	-	0.2585
	-	(-0.017)	-	(0.244)
Allocation Shortfall × r^{EUA} × Climate Policy Event	-	-	0.2220	-0.9878***
	-	-	(0.721)	(-3.046)
Firm FE	Yes	Yes	Yes	Yes
Country × Sector × Year FE	Yes	Yes	Yes	Yes
N.o. Obs.	2,392,451	2,392,451	2,392,451	2,392,451
R^2-Adj.	0.004	0.002	0.001	0.004

Table 12: What Drives the Carbon Price Sensitivity? Interactions with Firm Characteristics
This table reports results from estimating Equation (11). Variables are defined in Table A1. The sample period starts in 2005 and ends in 2023. Standard errors are two-way clustered at the firm and date level. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	Excess return					
Allocation Shortfall $\times$ r^{EUA}	-0.5941	-0.6084	-0.9737**	-0.9309	-1.3345**	-0.6297
	(-1.448)	(-1.180)	(-2.377)	(-0.596)	(-2.560)	(-1.128)
Emissions Intensity $\times$ Allocation Shortfall $\times$ r^{EUA}	-0.0415**	-	-	-	-	-
	(-2.088)	-	-	-	-	-
$P^{\text{EUA}}_{t\text{-}1}$ $\times$ Allocation Shortfall $\times$ r^{EUA}	-	-0.0335*	-	-	-	-
	-	(-1.642)	-	-	-	-
EU ETS Exposure $\times$ Allocation Shortfall $\times$ r^{EUA}	-	-	-1.4430	-	-	-
	-	-	(-1.466)	-	-	-
log(Market Capitalization) $\times$ Allocation Shortfall $\times$ r^{EUA}	-	-	-	-0.0603	-	-
	-	-	-	(-0.344)	-	-
ROE $\times$ Allocation Shortfall $\times$ r^{EUA}	-	-	-	-	-0.0041	-
	-	-	-	-	(-0.277)	-
Leverage $\times$ Allocation Shortfall $\times$ r^{EUA}	-	-	-	-	-	-2.8276*
	-	-	-	-	-	(-1.675)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
N. Obs.	1,359,440	1,387,475	1,054,241	1,387,475	1,601,924	1,387,475
R^2-Adj.	0.219	0.213	0.226	0.213	0.208	0.213

Table 13: What Drives the Carbon Price Sensitivity? Cash-Flows versus Discount Rates

This table reports results from regressing one-year-ahead changes in the implied cost of capital (ICC) and return on equity (ROE) on the variables used in earlier regression specifications. Note that in this setting, the data is reported at a monthly frequency, while in our other regression, we use daily data. The implied cost of capital is calculated according to the procedure laid out in Appendix C. Standard errors are two-way clustered at the firm and month level. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Dependent variable:	$\Delta ICC_{t:t+12}$	$\Delta ROE_{t:t+12}$	$\Delta ICC_{t:t+12}$	$\Delta ROE_{t:t+12}$	$\Delta ICC_{t:t+12}$	$\Delta ROE_{t:t+12}$
	(1)	(2)	(3)	(4)	(5)	(6)
Allocation Shortfall $\times$ r^{EUA}	0.9309*	-3.2909**	0.8083	-4.3508**	1.8784*	0.0592
	(1.675)	(-2.355)	(1.316)	(-2.456)	(1.725)	(0.036)
Allocation Shortfall	1.5032***	0.1297	1.5594***	-1.6727***	1.4956***	3.0693***
	(19.955)	(0.633)	(17.290)	(-5.440)	(11.109)	(12.362)
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Domicile	All	All	EU	EU	Non-EU	Non-EU
N.o. Obs.	56,416	62,858	35,156	39,350	21,260	23,508
R^2-Adj.	0.255	0.527	0.281	0.475	0.304	0.590

Appendix A - Supplementary Figures and Tables

Table A1: Variable Definitions
This table reports on the data sources and definitions of the variables used in our main analyses.

Variable	Description	Source*
Excess Return$_{i,t}$	Return for stock i in month t in excess of the risk-free rate, winsorized at 0.5% and 99.5% cut-off points.	FS + KFDL
ln(Market Cap.)$_{i,t-1}$	Natural logarithm of market capitalization (in millions of €), where market capitalization is defined as shares outstanding multiplied by the share price at the end of month *t-1*.	FS
B/M$_{i,t-1}$	Book to market ratio is the book value of equity divided by market capitalization at the end of month *t-1*, winsorized at 1% and 99% cut-off points.	FS
ROE$_{i,t-1}$	Return on equity is net income divided by total shareholders' equity in the previous year, winsorized at 1% and 99% cut-off points.	FS
Leverage$_{i,t-1}$	Total long-term and short-term debt divided by total assets at the of the previous year, winsorized at 1% and 99% cut-off points.	FS
Invest./Assets$_{i,t-1}$	Investment to assets is capital expenditures divided by total assets at the previous year, winsorized at 1% and 99% cut-off points.	FS
PP&E/Assets$_{i,t-1}$	Property, Plant & Equipment divided by total assets at the end of the previous year, winsorised at 1% and 99% cut-off points.	FS
Volatility$_{i,t-1}$	Volatility is the standard deviation of excess returns over a 1-year rolling window.	AC
Market Beta$_{i,t-1}$	Market beta is obtained by 1-year rolling window regression of stock i's daily returns on the Fama and French (1993) market factor.	AC + FS + KFDL
ln(Emissions)$_{i,t}$	Combined scope 1 and scope 2 emissions of the year *t-1* (in millions of tonnes of CO_2-equivalent), winsorized from above at 99% cut-off point.	TC
Emissions Intensity$_{i,t}$	Natural logarithm of combined scope 1 and scope 2 emissions of the year *t-1* (in millions of tonnes of CO_2-equivalent) scaled by prior year revenues, winsorized from above at 99% cut-off point.	TC
Verified Emissions$_{i,t}$	Aggregated sum of verified emissions in compliance year t over all installations owned by firm i at the end of year t	EUTL
Allocated Allowances$_{i,t}$	Aggregated sum of allocated allowances in compliance year t over all installations owned by firm i at the end of year t	EUTL
Allocation Shortfall$_{i,t}$	Non-allocated emissions divided by verified emissions at the firm level	EUTL
EU ETS Exposure$_{i,t}$	Aggregated sum of verified emissions in compliance year t over all installations divided by scope 1 emissions of the year *t-1* (in millions of tonnes of CO_2-equivalent)	TC + EUTL
r_t^{EUA}	Percentage change from day t-1 to t in the settlement price for the ICE ECX European Union Allowance front futures contract	FS
Climate Policy Event$_t$	Regulatory event update to the EU ETS	Känzig (2023)
Climate Policy Surprise$_t$	The change in the carbon price r_t^{EUA} on days where a regulatory announcement takes place and otherwise zero	Känzig (2023)

*FS = FactSet, KFDL = Kenneth French's Data Library, AC = Authors' Calculations, TC = S&P Trucost
EUTL = European Union Transaction Log

Figure A1: EU Emission Allowance Prices For Different Futures Contracts
The figure shows daily EUA spot prices over the period 2005 to 2023. ICE ECX FRONT denotes the ECX front future contract (available for 2005-04-22 to 2023-08-11) traded on ICE's European Climate eXchange and obtained from FactSet with FactSetID 'ECF-FDS'. EEX NEAR-TERM denotes the NDEX EEX near-term futures contract (available for 2005-04-22 to 2023-08-11) traded on the European Energy eXchange (EEX) and obtained from FactSet with FactSetID 'DEAU-FDS'. NDEX CTINUOUS denotes the NDEX continuous futures contract (available from 2008-02-04 to 2023-08-07) traded on EEX and obtained from FactSet with FactSetID 'ECF00-NDEX'. EUCARB SPOT denotes the EUCARB spot futures contract (available from 2008-04-09 to 2023-08-07) obtained from FactSet with FactSetID 'EUCARB-FDS'.

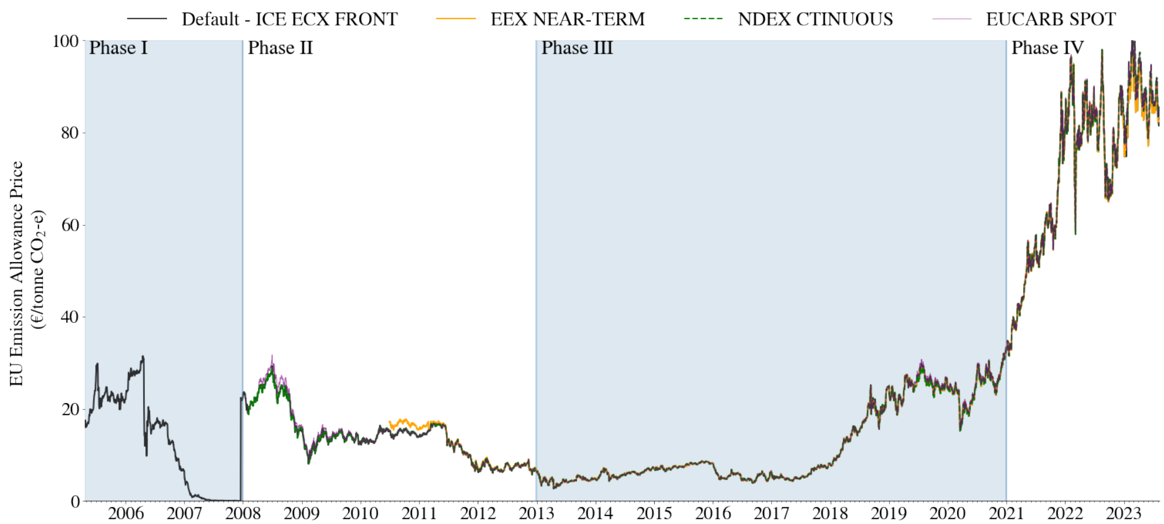


Table A2: Correlations in EAU Futures Prices
The table reports pairwise correlations between price returns of different futures contracts on the EUA. ICE ECX FRONT denotes the ECX front future contract (available for 2005-04-22 to 2023-08-11) traded on ICE's European Climate Exchange and obtained from FactSet with FactSetID 'ECF-FDS'. EEX NEAR-TERM denotes the NDEX EEX near-term futures contract (available for 2005-04-22 to 2023-08-11) traded on the European Energy eXchange (EEX) and obtained from FactSet with FactSetID 'DEAU-FDS'. NDEX CTINUOUS denotes the NDEX continuous futures contract (available from 2008-02-04 to 2023-08-07) traded on EEX and obtained from FactSet with FactSetID 'ECF00-NDEX'. EUCARB SPOT denotes the EUCARB spot futures contract (available from 2008-04-09 to 2023-08-07) obtained from FactSet with FactSetID 'EUCARB-FDS'.

	ICE ECX FRONT	EEX NEAR-TERM	NDEX CONTINUOUS	EUCARB SPOT
ICE ECX FRONT	1.00	-	-	-
EEX NEAR-TERM	0.96	1.00	-	-
NDEX CTINUOUS	1.00	0.96	1.00	-
EUCARB SPOT	0.99	0.96	0.99	1.00

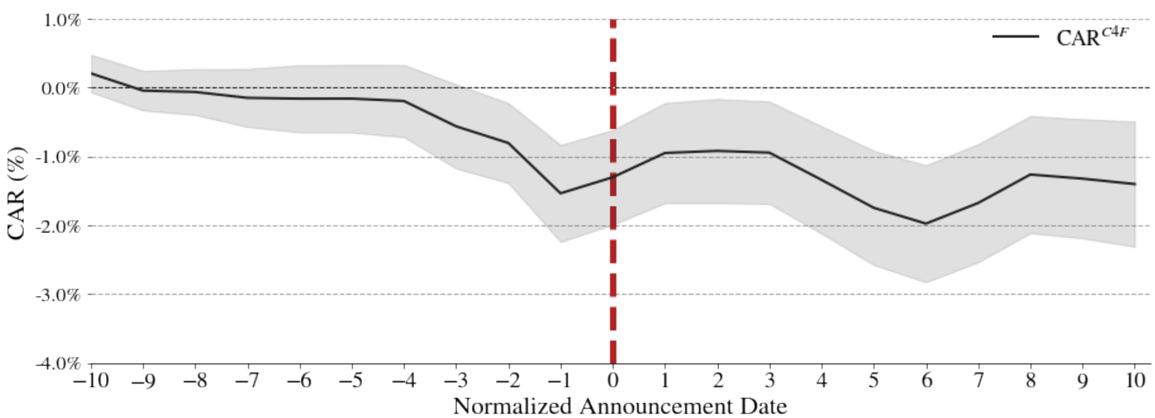
Table A3: EU ETS Compliance Cycle
This table reports the annual compliance cycle for the EU ETS. Regulated firms have to report emissions (supported by an accredited verifier) by the end of March for the year $t+1$, where t denotes the compliance year. Information on verified emissions is then released via the EUTL at the 'Verification Date' (typically the first business day of April). Regulated entities have to surrender EU allowances equal to their verified emissions for the year t by the last day of April of year $t+1$. A few days later, on the 'Compliance Date', the EUTL reports whether or not regulated entities are 'compliant', that is whether or not they surrendered sufficient allowances to cover their verified emissions.

Year	Phase	Verification Date	Compliance Date
2005	Phase I	2006-05-15	2006-05-15
2006	Phase I	2007-04-02	2007-05-15
2007	Phase I	2008-04-02	2008-05-15
2008	Phase II	2009-04-01	2009-05-15
2009	Phase II	2010-04-01	2010-05-17
2010	Phase II	2011-04-01	2011-05-16
2011	Phase II	2012-04-02	2012-05-15
2012	Phase II	2013-04-02	2013-05-15
2013	Phase III	2014-04-01	2014-05-15
2014	Phase III	2015-04-01	2015-05-04
2015	Phase III	2016-04-01	2016-05-02
2016	Phase III	2017-04-03	2017-05-02
2017	Phase III	2018-04-03	2018-05-02
2018	Phase III	2019-04-01	2019-05-02
2019	Phase III	2020-04-01	2020-05-04
2020	Phase III	2021-04-01	2021-05-04
2021	Phase IV	2022-04-01	2022-05-03
2022	Phase IV	2023-04-03	2023-05-04

Figure A2: Effect of EU ETS Non-Compliance – Sensitivity to Factor Model

This figure shows cumulative abnormal returns (CARs) of firms that are non-compliant with the EU ETS' regulations around the announcement of non-compliance. Estimates of CARs within the event window were obtained from Equation (6). Non-compliant firms are defined as listed firms that own at least one installation in compliance year t that fails to surrender sufficient allowances at the end of the compliance cycle. The CAR is calculated with respect to the Carhart (1997) 4-factor model in Panel A and with respect to the Fama and French (2015) 5-factor model augmented by the Carhart (1997) momentum factor in Panel B.

(a) CAR with respect to Carhart (1997) 4-factor



(b) CAR with respect to Fama and French (2015) 5-factor + Carhart (1997) momentum factor

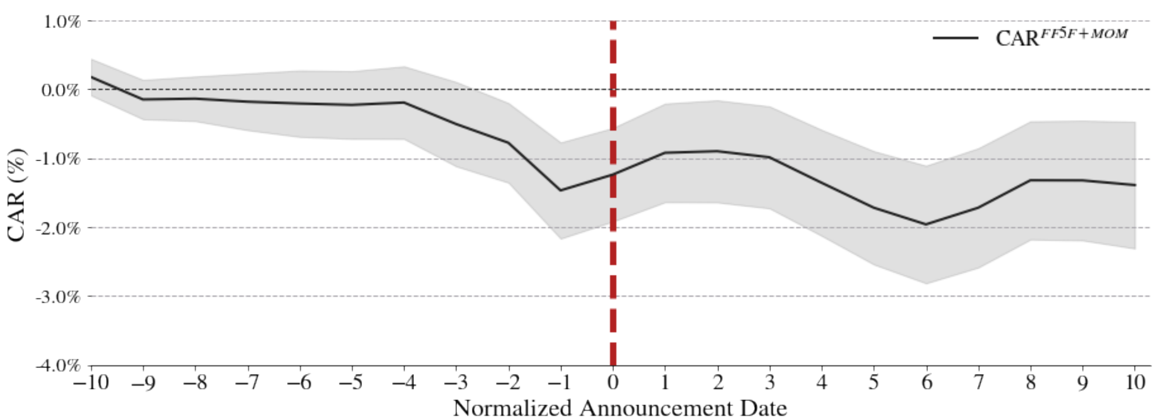


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TABLE A4: Känzig (2023) Regulatory Events & Carbon Policy Surprises

This table reports regulatory events used in the construction of the Carbon Policy Surprise Index. Regulatory events in Phase I and Phase II of the EU ETS were collected by Mansanet-Bataller and Pardo (2009) and are reported in Table A.1 of Känzig (2023). Events occurring in Phase II up to and before November 11, 2019, were collected by Känzig (2023) and are reported in Table A.1 of Känzig (2023). Events occurring between December 12, 2019, and May 31, 2021, were collected by Hengge, Panizza, and Varghese (2023) and are reported in Table A.2 of Hengge, Panizza, and Varghese (2023). Events occurring after June 29, 2021, were collected by the authors from press releases obtained via `https://ec.europa.eu/clima/news/news_archives_en`

Date	Regulatory Event
2005-05-25	Italian phase I NAP approved
2005-06-20	Greek phase I NAP approved
2005-11-23	Court judgment on a proposed amendment to NAP, UK vs Commission
2005-12-22	Further guidance on allocation plans for the 2008–2012 trading period
2006-02-22	Final UK Phase I NAP approved
2006-10-23	Stavros Dimas delivered the signal to tighten the cap of phase II
2006-11-13	Decision avoiding double counting of emission reductions for projects under the Kyoto Protocol
2006-11-29	Commission decision on the NAP of several member states
2006-12-14	Decision determining the respective emission levels of the community and each member state
2007-01-16	Phase II NAPs of Belgium and the Netherlands approved
2007-02-04	Austrian phase II NAP approved
2007-02-26	Spain phase II NAP approved
2007-03-26	Phase II NAPs of Poland, France and Czech Republic approved
2007-04-05	Estonian phase II NAP approved
2007-04-16	Hungarian phase II NAP approved
2007-04-30	Court order on German NAP, EnBW AG vs Commission
2007-05-02	Slovenia phase II NAP approved
2007-05-15	Italian phase II NAP approved
2007-07-11	Court judgment on German NAP, Germany vs Commission
2008-08-04	Court order on German NAP, Saint-Gobain Glass GmbH vs Commission
2009-04-23	Directive 2009/29/EC amending Directive 2003/87/EC to improve and extend the EU ETS
2009-09-23	Court judgment on NAP, Poland vs Commission
2009-12-24	Decision determining sectors and subsectors which have a significant risk of carbon leakage
2010-04-19	Commission accepts Polish NAP for 2008-2012
2010-07-14	Member states back Commission proposed rules for auctioning of allowances
2010-09-07	Commission takes the first step toward determining cap on emission allowances for 2013
2010-10-22	Cap on emission allowances for 2013 adopted
2010-11-25	Commission presents a proposal to restrict the use of credits from industrial gas projects
2010-12-11	Commission formally adopted the regulation on auctioning Auction
2010-12-15	Climate Change Committee supported the proposal on how to allocate emissions rights
2011-01-21	Member states voted to support the ban on the use of certain industrial gas credits
2011-03-15	Commission proposed that 120 million allowances be auctioned in 2012
2011-03-22	Court judgment on NAP, Latvia vs Commission
2011-03-29	Decision on transitional free allocation of allowances to the power sector
2011-04-27	Decision 2011/278/EU on transitional Union-wide rules for harmonized free allocation of allowances
2011-04-29	Commission rejects Estonia's revised NAP for 2008-2012
2011-05-12	Commission decision on revised Estonian NAP for 2008-2012
2011-07-06	Commission adopts ban on the use of industrial gas credits
2011-07-13	Member states agree to auction 120 million phase III allowances in 2012
2011-09-26	Commission sets the rules for allocation of free emissions allowances to airlines
2011-11-14	Clarification on the use of international credits in the third trading phase
2011-11-23	Regulation 1210/2011 determining the volume of allowances to be auctioned before 2013
2011-11-25	Update on preparatory steps for auctioning of phase 3 allowances
2012-02-05	Commission publishes guidelines for review of GHG inventories for setting national limits for 2013-2020
2012-03-29	Court judgments on NAPs for Estonia and Poland
2012-05-06	Commission publishes guidelines on State aid measures in the context of the post-2012 trading scheme
2012-05-23	Commission clears temporary free allowances for power plants in Cyprus, Estonia and Lithuania
2012-06-07	Commission clears temporary free allowances for power plants in Bulgaria, Czech Republic and Romania
2012-07-13	Commission rules on temporary free allowances for power plants in Poland
2012-07-25	Commission proposed to backload certain allowances from 2013-2015 to the end of phase III
2012-11-14	Commission presents options to reform the ETS to address growing supply-demand imbalance
2012-11-16	Auctions for 2012 aviation allowances put on hold
2012-11-30	Commission rules on temporary free allowances for power plants in Hungary
2012-12-11	Commission submits amendment to back-load 900 million allowances to the years 2019-2020

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TABLE A4: Känzig (2023) Regulatory Events & Carbon Policy Surprises (*cont'd*)
This table reports regulatory events used in the construction of the Carbon Policy Surprise Index. Regulatory events in Phase I and Phase II of the EU ETS were collected by Mansanet-Bataller and Pardo (2009) and are reported in Table A.1 of Känzig (2023). Events occurring in Phase II up to and before November 11, 2019, were collected by Känzig (2023) and are reported in Table A.1 of Känzig (2023). Events occurring between December 12, 2019, and May 31, 2021, were collected by Hengge, Panizza, and Varghese (2023) and are reported in Table A.2 of Hengge, Panizza, and Varghese (2023). Events occurring after June 29, 2021, were collected by the authors from press releases obtained via `https://ec.europa.eu/clima/news/news_archives_en`

Date	Regulatory Event
2013-01-25	Update on free allocation of allowances in 2013
2013-02-28	Free allocation of 2013 aviation allowances postponed
2013-03-07	The European Parliament voted for the carbon market back-loading proposal
2013-03-25	Auctions of aviation allowances not to resume before June
2013-04-16	The European Parliament voted against the Commission's back-loading proposal
2013-05-06	Commission submits proposal for international credit entitlements for 2013 to 2020
2013-05-09	Commission finalized decision on industrial free allocation for phase three
2013-07-30	Update on industrial free allocation for phase III
2013-08-11	Member states endorsed negotiations on the back-loading proposal
2013-09-26	Update on number of aviation allowances to be auctioned in 2012
2013-10-07	Member states approve the addition of sectors to the carbon leakage list for 2014
2013-10-12	European Parliament voted for the back-loading proposal
2013-11-12	Climate Change Committee makes progress on implementation of the back-loading proposal
2013-11-21	Commission submitted a non-paper on back-loading to the EU Climate Change Committee
2013-12-18	Commission gives green light for first member states to allocate allowances for calendar year 2013
2014-01-22	Commission proposed to establish a market stability reserve for phase V
2014-02-05	Commission published the number of international credits exchanged
2014-02-26	Commission gives green light for free allocation by all member states
2014-02-27	Back-loading: 2014 auction volume reduced by 400 million allowances
2014-03-13	Commission approves the first batch of international credit entitlement tables
2014-03-28	Commission approves the second batch of international credit entitlement tables
2014-04-04	Update on approval of international credit entitlement tables
2014-04-06	Auctioning of aviation allowances to restart in September
2014-04-07	Commission published the first update on the allocation of allowances from the New Entrants' Reserve
2014-04-11	Updated information on exchange and international credit use
2014-04-23	Commission approves final international credit entitlement tables
2014-05-05	Commission submits proposed carbon leakage list for 2015-2019
2014-08-01	Climate Change Committee agrees back-loading
2014-09-07	Climate Change Committee agrees proposed carbon leakage list for the period 2015-2019
2014-10-27	Commission adopts the carbon leakage list for the period 2015-2019
2014-11-04	Commission approves four more international credit entitlement tables
2015-04-05	Updated information on exchange and international credit use
2015-04-11	Updated information on exchange and international credit use
2015-07-15	Proposal to revise the EU emissions trading system for the period after 2020
2015-07-23	Commission publishes status update for New Entrants' Reserve and allocation reductions
2016-01-15	Commission publishes status update for New Entrants' Reserve
2016-02-05	Updated information on exchange and international credit use
2016-04-11	Updated information on exchange and international credit use
2016-04-28	Court judgment on free allocation in the EU ETS for the period 2013-2020
2016-06-23	Following court judgment, commission to modify cross-sectoral correction factor for 2018-2020
2016-07-15	Commission published a status update on the allocation of allowances from New Entrants' Reserve 2013-2020
2016-08-09	Court judgment on free allocation in the EU ETS for the period 2013-2020
2017-01-16	Commission publishes status update for New Entrants' Reserve
2017-01-24	Commission adopts Decision to implement Court ruling on the cross-sectoral correction factor
2017-02-05	Updated information on exchange and international credit use
2017-02-15	European Parliament voted in support of the revision of the ETS Directive for the period after 2021
2017-04-27	Climate Change Committee approves technical changes to auction rules
2017-06-11	Updated information on exchange and international credit use
2017-07-17	Commission publishes status update for New Entrants' Reserve
2017-07-26	Court judgment again confirms benchmarks for free allocation of ETS allowances for 2013-2020
2017-12-05	Commission publishes first surplus indicator for ETS Market Stability Reserve
2018-01-15	Commission publishes status update for New Entrants' Reserve
2018-04-05	Updated information on exchange and international credit use

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Table A4: Känzig (2023) Regulatory Events & Carbon Policy Surprises (*cont'd*)
This table reports regulatory events used in the construction of the Carbon Policy Surprise Index. Regulatory events in Phase I and Phase II of the EU ETS were collected by Mansanet-Bataller and Pardo (2009) and are reported in Table A.1 of Känzig (2023). Events occurring in Phase II up to and before November 11, 2019, were collected by Känzig (2023) and are reported in Table A.1 of Känzig (2023). Events occurring between December 12, 2019, and May 31, 2021, were collected by Hengge, Panizza, and Varghese (2023) and are reported in Table A.2 of Hengge, Panizza, and Varghese (2023). Events occurring after June 29, 2021, were collected by the authors from press releases obtained via `https://ec.europa.eu/clima/news/news_archives_en`

Date	Regulatory Event
2018-05-12	Poland's 2019 auctions to include some allowances not used for power sector modernization
2018-05-15	ETS Market Stability Reserve will start by reducing auction volume by almost 265 million allowances
2018-06-11	Updated information on exchange and international credit use
2018-07-16	Commission publishes status update for New Entrants' Reserve
2018-08-05	Commission Notice on the preliminary carbon leakage list for phase IV (2021-2030)
2018-10-30	Commission adopts an amendment to ETS auctioning regulation
2019-01-15	Commission publishes status update for New Entrants' Reserve
2019-04-23	EU ETS: Iceland, Liechtenstein, and Norway to start auctions on the auction platform soon
2019-05-15	ETS Market Stability Reserve to reduce auction volume by almost 400 million allowances between September 2019 and August 2020
2019-06-19	Updated information on exchange and international credit use in the EU ETS
2019-07-15	Commission publishes status update for New Entrants' Reserve
2019-10-31	Adoption of the Regulation on adjustments to free allocation of emission allowances due to activity level changes
2019-12-06	Poland's 2020 auction volume to include allowances not used for power sector modernization
2019-12-12	The start of auctioning for the Innovation Fund was postponed but no delay to the launch of the Innovation Fund
2020-01-15	Commission publishes status update for New Entrants' Reserve
2020-08-05	Updated information on exchange and international credit use in the EU ETS
2020-08-05	ETS Market Stability Reserve to reduce auction volume by over 330 million allowances between September 2020 and August 2021
2020-11-12	Further information on the start of phase 4 of the EU ETS in 2021: emission allowances to be issued for aircraft operators and the Market Stability
2021-03-15	Adoption of the Regulation determining benchmark values for free allocation for the period 2021-2025
2021-05-25	Updated information on exchange and international credits' use in the EU ETS
2021-05-31	Commission adopts the uniform cross-sectoral correction factor to be applied to free allocation for 2021 to 2025 in EU ETS Free alloc.
2021-06-29	Commission publishes the national allocation tables of Member States for EU ETS stationary installations eligible to receive a free allocation in the period 2021-2025
2021-11-15	Calendar 2022 for the execution of transfers between the emission trading registries of the EU and Switzerland
2021-12-05	ETS Market Stability Reserve to reduce auction volume by over 378 million allowances between September 2021 and August 2022 Auction
2022-04-25	Emissions trading: greenhouse gas emissions up by 7.3% in 2021 compared with 2020
2022-11-29	2023 arrangement for the execution of transfers between the emission trading registries of the EU and Switzerland
2022-12-05	ETS Market Stability Reserve to reduce auction volume by over 347 million allowances between September 2022 and August 2023 (update)
2022-12-21	European Green Deal: EU agrees to strengthen and expand emissions trading, and creates a Social Climate Fund to help people in the transition
2022-12-22	European Green Deal: new rules agreed on applying the EU emissions trading system in the aviation sector
2023-01-30	ETS Revision: no change to the deadline to surrender allowances in 2023

Appendix B - Matching Installations to Parent Companies

Information in the EUTL is registered at the installation level. As we are primarily interested in the stock market implications of the system, our analysis requires the aggregation of installation-level data to listed parent companies. In this section, we provide further information on the procedure we have followed to accomplish this goal.

B0.1 Matching EU ETS Installations to Subsidiary Firms

We start by pairing the installations in our sample with registered subsidiary firms. We rely on information from Bureau van Dijk's Orbis Global database to obtain such a mapping. Our procedure is twofold. First, we query company names listed in the EUTL and then rely on Bureau van Dijk's algorithm to obtain a match in Orbis. We restrict the algorithm to search only for company records within the reported installations' country to minimize the risk of incorrect matches.[13] In case our approach does not yield a matching subsidiary firm, we repeat the above procedure with account holder names rather than parent companies, and otherwise with installation names rather than account holder names.[14] This combined procedure results in a matching subsidiary firm for about 67.3% of installations in the registry, representing around 82.1% of total emissions in the EU ETS. Second, we leverage on the work by Letout (2022), who used national registration numbers to establish a link between installation in the EUTL and subsidiaries in Bureau van Dijk.[15] Combining our matching outcomes with those of Letout (2022)'s results in a registered subsidiary firm for about 96.1% of the installations in the EUTL, representing over 98.7% of total CO_2 emissions in the EU ETS. The few installations for which we do not find a registered subsidiary firm tend to be (local) government facilities such as hospitals and universities that are large enough to be regulated under the system but that are typically not associated with a registered company in Orbis.

B0.2 Matching Subsidiary Firms to Parent Companies

Our next step is to match subsidiary firms to parent companies so that we can aggregate emissions and allowances across installations owned by the same (listed) parent companies. Since our sample period covers the entire lifespan of the EU ETS from 2005 to 2024, we want to keep track of historically accurate ownership chains so that for each year of the EU ETS, we can accomplish an accurate

[13]A thorough inspection of the matching outcomes results in very few incorrect linkages that we subsequently correct manually using business registration and address details.

[14]Typically, a parent company can be associated with several accounts holders which again can be associated with several installations.

[15]These data are available for download at https://data.jrc.ec.europa.eu/dataset/bdd1b71f-1bc8-4e65-8123-bbdd8981f116

representation of aggregated emissions and allowances at the parent company. While Orbis reports a Global Ultimate Owner for all subsidiary firms in its database for exactly this purpose, this information is only based on current ownership structures and retrospectively revised whenever an ownership change occurs. The GUOs, as reported by Orbis, therefore, do not provide a historically accurate ownership link. We circumvent this issue by relying on an alternative, more elaborate procedure.

This procedure starts by retrieving end-of-year ownership shareholder information for all the subsidiary firms in our sample from Bureau van Dijk's Orbis Global.[16] Two types of ownership variables are available in the database: *direct* ownership percentages and *total* ownership percentages, where the latter refers to the accumulated combined ultimate ownership. We focus our analysis only on direct ownership since, in principle, total ownership can be derived from accumulating and aggregating direct ownership, and the inclusion of total ownership links leads to duplicate records. When converting reported ownership to numerical format, we implement several of the data cleaning steps proposed by Kalemli-Özcan et al. (2015): (i) replace direct ownership entries with a leading symbol such as “$<$”, “$>$”, and “$\pm$” with the number following the symbol, (ii) replace non-numeric special codes such as “WO” (wholly owned) with 100%, “BR” (branch) with 100%, “MO” (majority owned) with 50.01%, “CQP1” (50% + one share) with 50.01%, “JO” (jointly owned) with 50%, “NG” (negligible) with 0.01%, and “-” and “n.a.” with 0%, (iii) round ownership percentages to the nearest two digits, and (iv) remove duplicates when the sum of direct ownerships adds to more than 100%.

We then iterate over ownership chains to arrive at an ultimate owner based on a process similar to that of Jaraitė et al. (2013). This approach can be summarised as follows:

1. Start with a list of BvD IDs for all subsidiary firms linked to the sample of EU ETS installations;
2. For each BvD ID in this list, extract the BvD ID(s) of its shareholder(s) as of December for each year from 2005 to 2022;
3. For the shareholder's or shareholders' BvD ID(s), extract the BvD ID(s) of its shareholder(s) as of December for each year from 2005 to 2022;
4. Continue to query for shareholders of shareholders until no shareholders can be found;

Following the above procedure yields an extensive combination of subsidiary-to-shareholder linkages for each year in our sample. We impose several constraints when traversing the ownership tree. First, we remove certain 'illegal' shareholder types. A shareholder in Orbis can also be a private individual, a family, a foundation, or a government or governmental agency. We are primarily interested in linking subsidiary firms to ultimate *corporate* shareholders, even if this corporation is (partly) owned

[16] Orbis Global contains data on over 400 million private and public companies. Bureau van Dijk collects information from government and commercial information providers, from firms' disclosures, and from direct solicitations to populate its database.

by any non-corporate shareholders. Therefore, we traverse this ownership structure in reverse and remove non-corporate shareholders that occur at the end of a chain.[17] Second, since we link EU ETS exposures to stock returns, we are interested in linking subsidiaries to listed parent companies. We thus instruct the algorithm to return listed shareholders in combination with their shareholdings. Our cleaned file includes 209,384 unique ownership links, that is, unique combinations between a subsidiary firm and a shareholder, for 19,810 unique subsidiaries with 18,542 unique shareholders. Table B1 summarizes the outcome of this two-step matching procedure.

[17] For an example, consider Electricité de France (EDF) – the largest utility firm in France. EDF is majority-owned by the French government, and thus, BvD classifies the 'Government of France' as the ultimate owner of any of EDF's subsidiary firms. EDF SA is, however, also a listed firm, and our algorithm returns it as the ultimate corporate owner.

Table B1: Matching Installations to Listed Parent Companies
The table reports information on the matching of installations in the European Union Transaction Log (EUTL) to listed parent company firms. For every compliance year in the operational history of the EU ETS and for the full sample period (highlighted in bold) we report the number of installations with non-zero verified emissions, the total verified emissions of these installations (in million tonnes of CO_2-equivalent), and the total allocated allowances of these installations (in million tonnes of CO_2-equivalent). The matching procedure relies on a two-step process. First, installations from the EUTL are matched to subsidiary firms in Burea van Dijk's Orbis Global database. The outcome of this first step is reported under Matched to Subsidiary Firm. Here we report the number of installations for which we could establish such a match, the fraction of matched installations out of the total number of installations, their relative emissions out of total emissions and their relative allocations out of total allocations. In the second step, we follow a procedure similar to Jaraitė et al. (2013) to match subsidiary firms to historically representative listed parent companies. Similar information on the second-stage mapping procedure is reported under Matched to Listed Parent Firm. Our sample period spans all compliance years in the history of the EU ETS, spanning from 2005 to 2022 as the latest compliance year. The different operational phases of the EU ETS are seperated in the table below by alternating background colors.

	Installations in EUTL			Matched to Subsidiary Firm				Matched to Listed Parent Firm			
Year	Installations	Emissions (10^6 tns CO_2-e)	Allocations (10^6 tns CO_2-e)	Installations	Installations (%)	Emissions (%)	Allocations (%)	Installations	Installations (%)	Emissions (%)	Allocations (%)
2005	10,396	2,013.32	2,088.74	9,932	95.54	98.54	98.51	4,910	47.23	74.54	73.56
2006	10,663	2,035.21	2,059.42	10,191	95.57	98.50	98.51	4,995	46.84	74.97	74.39
2007	11,309	2,164.70	2,134.93	10,840	95.85	98.58	98.55	5,346	47.27	74.66	74.53
2008	11,305	2,119.76	1,957.91	10,924	96.63	98.63	98.48	5,598	49.52	74.66	71.62
2009	11,277	1,879.53	1,971.52	10,932	96.94	98.62	98.51	5,632	49.94	74.83	72.35
2010	11,267	1,935.74	1,997.68	10,951	97.20	98.63	98.54	5,570	49.44	72.29	71.13
2011	11,185	1,900.30	2,016.05	10,906	97.51	98.74	98.56	5,770	51.59	73.42	71.04
2012	10,914	1,862.45	2,053.28	10,655	97.63	98.81	98.58	5,684	52.08	72.64	70.04
2013	11,379	1,898.76	1,013.27	11,161	98.08	98.81	98.44	5,791	50.89	72.67	62.58
2014	11,037	1,796.53	939.27	10,831	98.13	98.82	98.53	5,764	52.22	72.01	62.86
2015	10,697	1,776.42	878.69	10,508	98.23	98.82	98.36	5,737	53.63	76.69	70.99
2016	10,472	1,718.61	833.32	10,294	98.30	98.74	98.35	5,886	56.21	77.10	71.61
2017	10,287	1,719.66	786.50	10,112	98.30	98.82	98.31	5,888	57.24	73.70	69.41
2018	10,192	1,646.24	748.46	10,019	98.30	98.76	98.28	5,962	58.50	75.32	73.87
2019	10,058	1,495.32	720.76	9,884	98.27	98.71	98.21	5,965	59.31	71.90	67.13
2020	9,814	1,331.94	674.13	9,641	98.24	98.69	98.18	5,972	60.85	72.44	68.99
2021	8,409	1,308.82	546.14	8,249	98.10	98.77	98.22	4,305	51.20	70.81	67.48
2022	8,236	1,275.84	538.46	8,066	97.94	98.87	98.17	4,280	51.97	72.67	67.44
Sample	**15,322**	**31,879.15**	**23,958.53**	**14,733**	**96.16**	**98.71**	**98.46**	**6,555**	**42.78**	**73.85**	**70.97**

Appendix C - Estimating the Implied Cost of (Equity) Capital

The implied cost of (equity) capital (ICC) is the internal rate of return that equates a firm's discounted future expected cash flows with its current stock price. ICCs are widely used in the accounting and finance literature as forward-looking estimates of expected returns. A popular approach to estimating ICCs is by using the model of Gebhardt, Lee, and Swaminathan (2001). In this model, a firm's stock price is based on the residual income model

$$P_t = BPS_t + \sum_{\tau=1}^{\infty} \frac{\mathbb{E}_t[EPS_{t+\tau}] - r_e \mathbb{E}_t[BPS_{t+\tau}]}{(1+r_e)^{\tau}}, \tag{12}$$

where P_{it} is the stock price, BPS_{it} is the book value of equity per share, EPS_{it} is the earnings per share, and r_e is the cost of equity capital.

We can substitute for the EPS in Equation (12), since $EPS = ROE \times BPS$. Rather than modeling the cash flows as an infinite series, we follow Chen, Da, and Zhao (2013) and model future free cash flows over 16 years and beyond that as a terminal value

$$P_t = BPS_t + \sum_{\tau=1}^{16} \frac{\mathbb{E}_t[ROE_{t+\tau} - r_e]BPS_{t+\tau-1}}{(1+r_e)^{\tau}} + \frac{\mathbb{E}_t[ROE_{t+16} - r_e]BPS_{t+15}}{r_e(1+r_e)^{15}} \tag{13}$$

A common approach in the ICC literature is to proxy for the expected future earnings per share using analyst earnings forecasts, which we denote by $FEPS_{i,t+\tau}$. We obtain from Institutional Brokers' Estimate System (I/B/E/S) consensus EPS forecast for years t+1 and t+2, and estimated long-term growth rates in earnings g_t.[18] The return on equity is calculated as

$$ROE_t = EPS_t / BPS_{t-1} \tag{14}$$

Earnings forecasts for the fiscal years t+3 to t+16 are derived from forecasts over the first two fiscal years following several assumptions. First, earnings growth is assumed to revert log-linearly from g_{t+3} to the long-term industry growth rate g_{t+3}^{IND} by year t+16 as in Pástor, Sinha, and Swaminathan (2008)[19]

$$g_{t+\tau} = g_{t+\tau-1} \times \exp\left(\ln(g_{t+3}^{\text{IND}}/g_{t+3})/13)\right) \;\; \forall \;\; 4 \leq \tau \leq 16 \tag{15}$$

[18] As standard in this literature, we impute missing EPS forecasts for fiscal years t+2 using the long-term growth rate and the prior year's forecast if available (e.g. $FEPS_{t+2} = FEPS_{t+1} \times (1 + g_{t+2})$), and equivalently missing long-term growth rates from the implied growth in adjacent consensus EPS estimates, if available (e.g. $g_{t+2} = FEPS_{t+2}/FEPS_{t+1} - 1$).

[19] We define industry growth rates by the firm's Fama and French (1997) industry classification as in Eskildsen et al. (2024).

As such, the earnings forecast for period $t + \tau$ is given by

$$FEPS_{t+\tau} = FEPS_{t+\tau-1} \times (1 + g_{t+\tau}) \;\; \forall \;\; 4 \leq \tau \leq 16 \tag{16}$$

Second, changes in book values are derived from clean-surplus accounting

$$BPS_t = BPS_{t-1} + EPS_t - DPS_t = BPS_{t-1} + EPS_t \times b_t \tag{17}$$

where DPS_t denotes the dividends per share and b_t is the plowback or retention rate. The second identity is derived from $DPS = EPS \times p$ and $b = 1 - p$, where p is the dividend payout ratio. Plowback rates are assumed to linearly mean revert to a steady state value computed from the sustainable growth formula (see Pástor, Sinha, and Swaminathan, 2008, for further details).[20] The dividend-payout ratio is assumed constant over the forecasting horizon and calculated using the dividend payments in Compustat normalized by earnings. For firms with negative earnings, we follow Gebhardt, Lee, and Swaminathan (2001) and calculate the dividend payout ratio from current dividends and a fraction of total assets set to 6%.

For each month and each firm in our sample, we obtain the required data from I/B/E/S and Compustat Global and Compustat North America. All stock prices and per-share financial data are adjusted for stock splits. We solve Equation (13) numerically. If multiple roots exist, we choose the lowest one.

[20] Plowback rates mean-revert linearly rather than log-linearly as they are observed to revert more slowly than growth rates by Pástor, Sinha, and Swaminathan (2008).