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No text in this thesis has been generated or suggested using AI. We have used AI (Chat GPT, GPT UiO) to improve the text and (Grammarly) to suggest grammatical or spelling corrections, and used our discretion to accept or reject any of the suggestions. We have used AI tools to suggest or improve part or all the code in the computer programs used to conduct the research reported in this thesis. These AI tools were Chat GPT, GPT UiO.

Abstract

This thesis investigates the impact of the European Union Emissions Trading System (EU ETS) on the firm value of companies listed on the STOXX 600 Europe index, using Tobin's Q as the valuation metric. Covering the period from 2012 to 2022, the research spans the three latter phases of the EU ETS, focusing on 827 firms. EU Allowance (EUA) prices are used as the primary independent variable to assess the influence of the EU ETS, complemented by various financial indicators to make the results more accurate. The empirical results indicate that while the EU ETS correlates positively with the broader European market, it has a distinctly negative impact on firms directly subject to the system. This trend is more pronounced when considering the costs of emissions and the volatility of EUA prices. After the introduction of the Market Stability Reserve (MSR) in 2019, subject firms are shown to decrease in value compared to the wider market. Furthermore, the study relates the empirical findings to the possibility of asset stranding induced by a stringently evolving ETS. These findings underscore the need for policies that facilitate a transition to a low-carbon economy, supporting industries in mitigating financial risks associated with environmental compliance.

Abbreviations

Full Name	Abbreviation
Carbon Dioxide	CO2
Carbon Disclosure Project	CDP
Conference of the Parties	COP
Consumer Discretionary	Consumer (D)
Consumer Staples	Consumer (S)
Cost of Emissions	COE
Difference-in-Difference	DiD
Earnings Before Interest, Taxes, Depreciation, and Amortization	EBITDA
Emissions Trading System	ETS
Europe Economic Area	EEA
Europe Union Emissions Trading System	EU ETS
European Central Bank	ECB
European Energy Exchange	EEX
European Union	EU
European Union Allowances	EUA
European Union Allowances Volatility Variables	EUAVOL
European Union Emissions Trading System	EU ETS
Fixed Effects	FE
Generalized Least Squares	GLS
Global Greenhouse Gas	GHG
Hamburg World Economic Institute	HWWI
Heteroskedasticity-Consistent	HC
Industry Classification Benchmark	ICB
Kyoto Protocol	KP
Least Squared Dummy Variables	LSDV
London Stock Exchange Group	LSEG
Market Stability Reserve	MSR
Nationally Determined Contributions	NDC
Natural Logarithm	Ln
Net Present Value	NPV
Nitrous Oxide	N2O
Ordinary Least Squares	OLS
Orthogonal EUA and fundamental driver's variable	REUA
Paris Agreement	PA
Perfluorocarbons	PFCs
Return of Capital	ROC
United Nations Framework Convention on Climate Change	UNFCCC
United States	US
Variance Inflation Factors	VIF

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1 Introduction and Motivation

Since the inception of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, the world has tried to develop and ratify climate policy both at the international and regional levels. These initiatives aim to limit global greenhouse gas (GHG) emissions and create a state in which humans and our natural climate system can coincide (UNFCCC-Secretariat, n.d.). In 2015 at the 21 Conference of the Parties (COP) in Paris, building upon the foundations established by the Kyoto Protocol (KP), the 196 member states of the UNFCCC agreed upon a landmark accord in which they would commit to limiting global temperatures to 2°C above pre-industrial levels, preferably 1.5°C. This is known as the Paris Agreement (PA). Like the KP, the PA ensures political feasibility by allowing each member state to contribute towards the 2°C goal through their Nationally Determined Contributions (NDC) (UNFCCC-PA, n.d.). So far, if measured by the total annual growth of GHG emissions and rises in global temperatures, our collective efforts have not achieved the desired outcome of sustainable coexistence (Ritchie et al., 2023).

The European Union (EU), in accordance with its legally binding individual emissions reduction targets from the KP, adopted the EU ETS Directive in 2003 and launched the EU Emissions Trading System (EU ETS) in 2005 (EC-Development.EU.ETS, n.d.). Given its status as one of the EU's key policies in fighting climate change, its continual stringent evolution through four phases, and as the world's largest carbon emissions trading system, analysing the impact of the EU ETS on the value of participating firms is highly pertinent. Thereby, it is of interest to investigate and acquire insight into the effectiveness of such a significant policy tool in influencing corporate behaviour and emissions reduction efforts. Our research question is therefore:

"Has the implementation of the EU ETS adversely impacted the financial value of European companies? Furthermore, in cases where these companies have not diversified or adapted sufficiently, are their assets at increased risk of becoming stranded?"

1.1 EU Emissions Trading System

1.1.1 Theory and Origins

The theory of internalizing negative externalities from pollution through policy initiatives and reaching an optimal targeted level of emissions at the least cost stems from the principles of a Pigouvian tax. The usual market equilibrium case states that the market clears when the marginal benefits of a good equal its marginal cost, materializing a in a Pareto efficient market where no one is better off from added goods being produced. Yet, with emitting entities, the true cost of producing is not captured as society is exposed to negative externalities. A Pigouvian tax tackles this added cost by setting a tax equal to the marginal social cost, incorporating both the production cost and social damages, resulting a new optimal amount of production (Jaeger, 2013). Richard Coase's 1960 paper "The Problem of Social Cost" (Coase, 1960), built on the concept by stating that private individuals, given well defined property rights and the absence of transaction costs, could themselves solve the effects of negative externalities by bargaining (Hahn & Stavins, 2010).

Both an optimal emissions tax and Coasian bargaining, although theoretically possible as policy tools, are presented with multiple hindrances. First, identifying an optimal emissions tax poses informational challenges to the true benefits and costs of polluting. Second, the political pressures from both consumers and producers alike make added taxes difficult to implement, the practical result from such initiatives are that firms are both burdened with abatement costs and taxes, which are then passed on to consumers (Hahn & Stavins, 2010). In the case of bargaining, the challenges are clearly defining tradeable property rights to environmental resources such as water and air. Furthermore, negotiation, enforcement and monitoring of agreements all take time and resources. Added to this is informational asymmetry, where parties have differentiating knowledge of the impact of their activities on the environment and can therefore leverage their informational advantages (Tresch, 2023). A policy tool that addresses these challenges, is politically feasible and tackles environmental damage at the least cost is an allowance cap-and-trade system.

An allowance cap-and-trade system operates by establishing a maximum limit on emissions, known as a 'cap'. This cap is translated into emission allowances, each typically representing the right to emit one tonne of CO2 or equivalent GHG. These allowances can be distributed in two main ways, by auctioning, which provides a double dividend in terms of tax revenue and reduced emissions. The alternative is distributing them for free based on historical emissions, otherwise known as "grandfathering" (C2ES, n.d.). Firms will in theory trade their allowances until the marginal cost of abatement equals the marginal benefit of emitting. The benefits of the system are as follows: governments can set a targeted emissions cap without knowing where the reductions occur, therefore also implying that knowledge of firm specific technology is not needed. Firms are therefore given flexibility in whether to buy allowances or innovate (WRI, n.d.). Furthermore, there is no need for setting a predetermined price on emissions, as market fluctuation induced by the supply and demand for allowances, and each firm cost of abatement determine the price of emissions, thereby also allowing for long term economic adaptability (Brookings, n.d.). Lastly, a cap ensures environmental certainty in the quantity of emissions and provides a steady framework for reaching future reduction targets.

1.1.2 EU ETS

Building on the foundational concepts of an allowance cap-and-trade system, it is prudent to focus on the EU ETS's structure and application. Introduced in 2005, the EU ETS is the world's largest emissions trading system, spanning all EU and EEA member states. Participation is mandatory for sectors emitting CO2, including electricity and heat generation, energy intensive industry, aviation, and maritime transport (as of 2024). Entities emitting nitrous oxide and perfluorocarbons are also included. In total, the system covers emissions from 10,000 installations, or about 40% of the EU's emissions (EC-Scope.EU.ETS, n.d.).

Since its inception in 2005, the system has gone through four phases. Phase 1 (2005-2007) was a trial phase to build a reliable market mechanism and prepare the system for aligning with the goals of the KP. Initial industry included power generation and energy intensive manufacturing with allowances being allocated for free. The cap was set based on estimates, as reliable emissions data was not yet available, resulting in a surplus of allowances and an ineffectual market. Prices eventually fell to zero in 2007 as supply exceeded demand. Phase 2 (2008-2012) linked the system to the emission reduction targets of the KP, introduced a lower cap based on emissions data from Phase 1 and reduced the proportion of free allowances. Ultimately, the demand for allowances would be reduced following the 2008 financial crisis, again resulting in an ineffective market and low carbon prices. Phase 3 (2013-2020) brought with it considerable changes, setting an EU-wide cap that reduced by 1.74% annually, introduced auctioning as the default method of allowance distribution, alongside free allocation, and incorporated more sectors and gases. Phase 4 (2021-2030) introduced a larger reduction rate of 2.2%, aligning the EU ETS with the broader policies of the EU Green Deal and the 2030 goal of 55% reduction in GHG emissions. As of 2021, there were 1.57 billion allowances on the market, of which 57% are auctioned, the rest being allocated for free (EC-Development.EU.ETS, n.d.). Additional policy instruments introduced in Phases 3 and 4 are the Innovation and Modernisation funds, created to direct auction revenues towards commercial energy innovation and to support lower income member states in transitioning. Also, the Market Stability Reserve (MSR) , created to adjust supply and counteract surplus allowances in circulation, fostering market and demand side stability (EC-Development.EU.ETS, n.d.).

2 Literature Review

This section presents previous literature on stranded assets and the EU ETS. Regarding the latter, the literature indicates a varied effect on firm valuation and various financial measures across industries, locations, and periods.

2.1 Stranded Assets

In examining the impact of the EU ETS on firm valuation, our research extends to contextualize this within the concept of stranded assets. This approach allows us to explore how the EU ETS influences asset value in the face of evolving environmental policies and the shifting energy landscape. According to the Annual Review of Environment and Resources, stranded assets can be defined as "assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities" (Caldecott et al., 2021, p. 418). For this thesis, it is fundamental to consider that all company's assets are subject to both physical and transition risks. Physical risk refers to "the risks to assets, companies, or portfolios resulting from physical weather phenomena caused or exacerbated by climate change" (Caldecott et al., 2021, p. 419). On the other hand, transition risk refers to the risks that result from "economic and societal changes required to transition to a sustainable economy with net-zero carbon emissions" (Caldecott et al., 2021, p. 419).

Considering transitional risk in the context of policy tools and fossil fuels, three concepts appear: "Unburnable carbon", a "carbon bubble" and the "Green Paradox" (Caldecott et al., 2021). The concept of unburnable carbon suggests that to meet the targets of the Paris Agreement, hence adhering to a carbon budget aimed at the 2°C target, one third of oil reserves, half of gas reserves and 80% of coal reserves must remain unextracted (Van Der Ploeg & Rezai, 2020). This builds the argument that a substantial amount of fossil fuel assets and their specific, non-adaptable infrastructure, are at risk of being stranded. In parallel, the concept of a carbon bubble suggests that investors, fossil fuel firms and a diverse category of dependent and interlinked industries are heavily exposed to overvalued fossil fuel assets, hence creating a theoretical carbon bubble (CTI, n.d.). Finally, the concept of the green paradox suggests that the anticipation of imminent climate policies, or the implementation of poorly crafted climate regulations, can lead to an increase in fossil fuel consumption in the short term. This surge occurs as producers rush to maximize the value of their assets before more stringent environmental restrictions come into effect (Jin & Zhang, 2019). However, Jin and Zhang, 2019 suggest that this phenomenon, and unnecessarily high rates of stranding, can be mitigated with well-designed policy that diverts the capital produced from fossil fuels towards green investments. Considering these theoretical concepts, the focus now shifts to the real-world impact of stranded fossil fuel assets and the growing awareness of climate change's far-reaching consequences.

Three empirical studies find the effect of transitional asset stranding risk for fossil fuel firms induced by a broader focus on climate change and related policies. Delis et al., 2019 find that between 2002 to 2016, syndicated loans for firms with fossil fuel reserves have higher interest rate than non-fossil fuel firms. This effect was even more pronounced in cases where: i) firms had greater exposure to reserves that could potentially become unburnable, ii) they operated in countries with stringent climate policies, iii) were located near coastlines, and iv) if the banks were labelled as "green". The trend of higher loan rates became especially noticeable following the 2015 PA. These result show that banks price-in the risk of fossil fuel reserves becoming stranded. Atanasova and Schwartz, 2019 study the effect of growth in oil reserves and firm value for 600 US fossil fuel firms between 1999 to 2018. They found that although oil reserves are a key component of firm value, the growth of underdeveloped reserves negatively impact firm value, especially when: i) firms have high extraction costs, ii) located in jurisdictions with stringent climate policy and, iii) after the 2015 PA. This suggests that markets penalize firms for having potentially unburnable reserves due to the risk of climate policy. Lastly, Matsumura et al., 2014, by assessing carbon emissions data from the CDP reports of S&P 500 companies, found that an increase in emissions is negatively associated with firm value. This is connected to stranded assets as companies that invest in high emitting projects could be penalized by investors becoming more aware to the costs associated with emissions and as the disclosure of emissions becomes stricter. Like Matsumura et al., 2014 which analysed firms from the S&P 500, Perdichizzi et al., 2024 examined companies listed within the EU from 2008 to 2022, they also find a negative association between CO2 emissions and market value.

2.2 The EU ETS

Having established the theoretical basis for asset stranding connected to carbon and climate policy, our focus shifts to studying the effect of the EU ETS on firm valuation. We show that previous literature has struggled to explain the causal effects of the ETS on firm value.

Veith et al., 2009 find that returns on common stock are positively correlated with European Union Allowances (EUA) prices, indicating that power companies profited from freely allocated EUAs in Phase I. Other studies like Commins et al., 2011 discovered that energy taxes and the EU ETS had a significant negative effect on return-on-capital (ROC) for European firms between 1996 and 2007. Yu, 2011 found a significant negative effect on the profit margins of electricity and district heating firms in Sweden for the first 2 years of the EU ETS. Mo et al., 2012 did a comparative study on the firm value of Europe's largest conventional electricity producers in ETS Phase 1 and 2. They found that in Phase 1, stock price changes positively correlated with price changes in EUA, suggesting an appreciation in firm value. In contrast, in Phase 2, with a stricter allowance allocation system, firm value negatively correlated with EUA price variations, suggesting a depreciation of firm value. More recent studies have produced different results, Jaraitė and Maria, 2016 showed that the EU ETS did not represent a drag on the profitability of participating firms between 2003 and 2010. Supplementing the previous finding, Aus Dem Moore et al., 2019 examined the causal relationship between the EU ETS and the fixed asset holdings of European firms subject to the system between 2005 to 2012. Their aim was to determine whether the EU ETS prompted firms to reallocate assets outside Europe. Contrary to the hypothesis that the EU ETS would lead to a reduction in European asset bases, their findings indicated an increase in the asset holdings within Europe, suggesting a positive impact of the EU ETS on the continent's economic asset base. Lastly, Clarkson et al., 2015 explore the impact of the EU ETS from an emissions perspective. They find the scheme only negatively influences firm value when a company's emissions surpass its allocated allowances, and these additional costs cannot be passed on to consumers. Additionally, they note that these findings are not homogeneous across firm and industries, with less competitive sectors being less affected.

Cumulatively, these papers suggest that poorly implemented allowance allocation results in mixed effects on firm value, indicating the need for more stringent policy after Phase 1 & 2 to incentives abatement and innovation. The literature's time frames also motivate researching the effects of Phase 3 & 4, as they were designed to mitigate mixed firm impact and a fluctuating market mechanism.

3 Methodology

3.1 Methodology and Hypothesis Development

This chapter present our hypothesis development for investigating our research question and its corresponding research design.

To answer the question: *"Has the implementation of the EU ETS influenced the financial value of European companies? Furthermore, have the firms subject to the EU ETS been negatively affected by its implementation and stringent evolution, or have possible measures to innovate and abate mitigated the negative effects of an increasing carbon price?"*, the following testable hypothesis were developed:

- Hypothesis 1: "European firm value is negatively related to EUA prices".
- Hypothesis 2: "EU ETS subject firm value is negatively related to EUA prices".
- Hypothesis 3: "EU ETS subject firm value is negatively related to the cost of emissions".

  Model using a Difference-in-Difference approach:
- Hypothesis 4: "EU ETS subject firm value has had a differential and negative trend to non-subject firms following the introduction of the Market Stability Reserve".

3.2 Model Selection

In this section we will briefly outline the composition of our data sample and detail our model selection process. This process will help us in determining the appropriate model to address our research question and subsequent hypotheses.

3.2.1 Panel Data

The dataset consists of STOXX 600 Europe firms spanning 11 years, allowing it to encompass both time-series and cross-sectional elements. The data is structured as an unbalanced panel, meaning not all entities have available information across our sample period (Brooks, 2019). There are several advantages to using a panel data structure compared to time-series and cross-sectional data. First, panel data controls for individual heterogeneity and thereby captures unobserved differences between entities, such as firm specific factors. Thereby the analysis controls for unobserved variables that could affect the firm value and mitigate omitted variable bias (Baltagi, 2008). Second, by combining time series and cross-sectional data, panel data provides more observations, degrees of freedom, and variability, leading to enhanced statistical power and mitigation of issues related to multicollinearity. This allows for a better dynamic assessment of the relationship within and between firms over time. The combination of time-series and cross-sectional elements also allows for capturing temporal dynamics, particularly useful in studying the effects of policies like the EU ETS. The alternative would be a large set of pure time series data, which, while capturing the temporal dynamics, misses cross-sectional variation. Given the EU ETS has only been effectual for a short period, panel data offers a better structure for capturing its impact across different firms, adding statistical power to its effect on firm value.

3.3 Model Choice

When using panel data, there a several models that can be employed. For this thesis, pooled OLS, fixed effects and random fixed effects models have been considered. In this section the different models are described.

3.3.1 Pooled Regression

A pooled regression consists of estimating a single equation on all data together, so that the dataset for the dependent variable is stacked into a single column containing all the cross-sectional and time series observations (Brooks, 2019). Using a pooled regression model possesses the advantage of utilizing large sets of data, providing a broad overview of the relationships between variables. Additionally, the method potentially aids in mitigating issues related to multicollinearity and omitted variable bias. However, the model assumes homogeneity across the dataset, presuming that the average values and the relation between the variables remain constant over time and for every cross-sectional observation from the data. Considering the nature of the Europe Stoxx 600 and its constituent's relationship with evolving emissions related variables, a basic pooled model might fail in capturing entity specific or temporal dynamics. A pooled regression for our study would use following model:

$$\text{Tobin's } Q_{i,t} = \alpha_{i,t} + \beta_1 \text{EUA}_{i,t} + \beta_2 \text{Dividend}_{i,t} + \beta_3 \text{CapEx}_{i,t} + \beta_4 \text{Size}_{i,t} \\ + \beta_5 \text{Profitability}_{i,t} + \beta_6 \text{Market Leverage}_{i,t} + \mu_{i,t}$$

3.3.2 Fixed effects

The fixed effects model captures the unobserved heterogeneity, i.e. all variables that effect the dependent variable cross-sectionally, but that do not change over time. This is done by decomposing the error term into time-invariant individual effects and a remainder disturbance term which varies over time and entities (Brooks, 2019). The decomposition is as follows:

$$u_{i,t} = \mu_i + v_{i,t}$$

Two possible approaches for using a fixed effects model are using least squared dummy variables (LSDV) and within transformation. When using LSDV, dummy variables are included for all firms, capturing the time-invariant individual effects from each entity. A point of notice is that the intercept (α) is removed to avoid perfect multicollinearity between the dummy variable and the intercept, also known as the dummy variable trap. A common challenge with LSDV is that if the number of entities "N" is large, many parameters would need to be estimated, requiring substantial computational resources. A simplified method is the within transformation. This entails subtracting the time-mean from the values of each variable, resulting in a regression model that only contains demeaned variables. Again, the intercept is removed as the dependent variable has zero mean. The model becomes:

$$\text{Tobin's } \ddot{Q}_{i,t} = \beta_1 E\ddot{U}A_{i,t} + \beta_2 Divi\ddot{d}end_{i,t} + \beta_3 Ca\ddot{p}Ex_{i,t} + \beta_4 Si\ddot{z}e_{i,t} + \beta_5 Profit\ddot{a}bility_{i,t} + \beta_6 Market\ddot{L}everage_{i,t} + u_{i,t}$$

Where the two dots on top of the coefficients refer to the demeaned values. A disadvantage with using the within transformation method is that the ability to investigate individual effects (ui) that effect the dependent variable, but do not vary over time.

3.3.3 Random effects

The random effects model, like the fixed effects model, also incorporates an individual intercept for each cross-sectional observation. However, it extends this by adding a unique random component which "varies cross-sectionally but is constant over time" (Brooks, 2019, p. 637). The random effects model is represented by the following equation:

$$Y_{i,t} = \alpha + \beta X + \omega_{i,t}, \ \omega_{i,t} = \epsilon_{i,t} + v_{i,t}$$

Where $\epsilon_{i,t}$ "measures the random deviation of each entity's intercept term from the 'global' intercept term (α)" (Brooks, 2019, p. 637). Thereby, the complete random effects equation becomes:

$$\text{Tobin's } Q_{i,t} = \alpha_{i,t} + \beta_1 \text{EUA}_{i,t} + \beta_2 \text{Dividend}_{i,t} + \beta_3 \text{CapEx}_{i,t} + \beta_4 \text{Size}_{i,t} + \beta_5 \text{Profitability}_{i,t} + \beta_6 \text{Market Leverage}_{i,t} + \omega_{i,t}$$

One drawback of using a random effects model is that the parameters are not efficient for using OLS and a GLS transformation must be applied. In addition, the approach is "more appropriate when the entities in the sample can be thought of as having been randomly selected from the population" (Brooks, 2019, p. 638). Given that the entities in our sample are not randomly selected but relatively fixed constituents of the Europe Stoxx 600 index, using a random effects model could produce biased estimations.

3.4 Final model

Following the discussions on pooled OLS, fixed effects and random fixed effects models, we have decided a pooled OLS model with LSVD is most suitable for investigating the EU ETS broader impact on Europe Stoxx 600 firms. This approach capitalizes on the pooled OLS strengths of giving a broad understanding of variable relationships, while addressing its limitation of assuming heterogeneity across the dataset. Unlike the within transformation fixed effects model, which focuses on within-entity variation and removes the intercept, thereby solely focusing on changes relative to each entities mean, pooled LSDV allows us to maintain an intercept. This inclusion enables us to capture both the average impact of the independent variables and the specific influence of time and industry sectors effects on firm value. To conclude, by using dummy variables for both time periods and industry sectors, we can control for specific dynamics while assessing the broader average influence of emissions related variables on Europe Stoxx 600 firms. The models for the pooled LSDV becomes:

$$\text{Tobin's } Q_{i,t} = \alpha_{i,t} + \beta_1 \text{EUA}_{i,t} + \beta_2 \text{Dividend}_{i,t} + \beta_3 \text{CapEx}_{i,t} + \beta_4 \text{Size}_{i,t} + \beta_5 \text{Profitability}_{i,t} + \beta_6 \text{Market Leverage}_{i,t} + \lambda_i + \lambda_t + \mu_{i,t}$$

Where λ_t represents the time fixed effect dummy and λ_i represents the industry fixed effect dummy.

3.4.1 Individual Effects Test:

To ascertain whether the inclusion of time or industry effects significantly enhances the model, an F test for individual effects is performed (Baltagi, 2008). The test aids in determining if the additional variables improve the model's explanatory power compared to the basic pooled OLS model. The restricted model represents the basic pooled OLS model without dummies, whereas the unrestricted model represents the pooled OLS model with dummies. The null and alternative hypotheses are:

$$\text{H0: } \beta_{time} = 0 \; or \; \beta_{industry} = 0$$
$$\text{H1: } \beta_{time} \neq 0 \; or \; \beta_{industry} \neq 0$$

Where the null hypothesis denotes that there are no individual effects present, and a pooled model is appropriate. Thereby, if null hypothesis is rejected, individual effects are present and a model with fixed effects is preferable.

3.4.2 Difference in Difference model

When analysing the EU ETS price evolution, the period between 2018 – 2019 acts as a crucial point for when the systems market mechanisms begin to have a tangible impact. This represents an accumulation of wider EU and EU ETS policy implementations. As a contributor and a proxy for an exogenous shock which resulted in a change in market effectiveness, the introduction of the MSR in January 2019 has been chosen as a reasonable cut off point to test Hypothesis 4. A Difference-in-Difference (DiD) estimation is used to isolate the effect of the policy implementation of the MSR on European firm value.

To conduct the DiD, two groups must be constructed. The group exposed to the implementation of the MSR is known as the treatment group, which consists of EU ETS subject firms categorized by their Carbon Disclosure Project (CDP) report statements of inclusion. The non-exposed group is known as the control group and consists of all firms that report their exclusion. Further details on sample composition can be found in chapter 4.1. In addition, a pre and post treatment period must be defined. The pre-treatment period consists of the timeframe 2012 to 2018. The post-treatment period consists of the timeframe 2019 to 2022. A critical prerequisite for conducting the DiD is that both groups share parallel trends prior to the introduction of the MSR. Table 1 provides a detailed explanation of the DiD model setup:

Table 1: DiD Model Setup

Implementation effect of MSR	Pre 2019 (A = 0)	Post 2019 (A = 1)	Difference (A = 1 - A = 0)
ETS-subject firms (T = 1)	$\alpha+\beta$	$\alpha+\beta+\delta+\psi$	$\delta+\psi$
Non-ETS-subject firms	α	$\alpha+\delta$	δ
Treatment - control	β	$\beta+\psi$	ψ

Where:

- α: Represents the intercept.
- β: Represents the difference between ETS-subject firms and non-ETS-subject firms.
- δ: Represents the implementation effect the MSR has on both groups.
- Ψ: Represents the differential impact of the MSR on ETS-subject firms in comparison to non-ETS-subject firms.

4 Data

In this chapter, we will present the process of selecting the sample of firms used in this study. Following that, the variables used to answer our research question and subsequent hypotheses will be described.

4.1 Sample

The sample for this thesis consists of all constituents from the Stoxx Europe 600 Index. The index has a fixed number of 600 member stocks which are reviewed and updated quarterly for inclusion or exclusion, thereby, firms that have joined or left the index in the sample period must also be included to avoid survivorship bias. The constituents represent large, mid, and small capitalization firms spanning 17 European countries and 11 sectors classified by the Industry Classification Benchmark (ICB). The index employs a free-float market capitalization weighting system, with each constituent's weight being determined by its adjusted market capitalization for free-float. This approach ensures the index accurately reflects European market dynamics based on publicly traded shares, surmounting to approximately 90% of the underlying investible equity market being represented (STOXX, n.d.). The index's wide and accurate market representation provides a suitable sample to evaluate the effects of the EU ETS.

The data was collected using Datastream provided by the LSEG Workspace database (previously known as Refinitiv Workspace). The database offers historical financial data on 107,000 active equities across 100 different markets, providing 50 years of data for prominent developed markets (LSEG, n.d.). The historical data collected for each constituent covers the period from 01.01.2012 to 01.12.2022. This time frame encompasses the final year of the ETS Phase 2, the entirety of Phase 3, and the two initial years of Phase 4. Between 2012 to 2022, the total number of firms in the index constituted 827. Table 2 shows the ICB industry composition of the STOXX 600 constituents list per 2022, including firms that have been included or excluded throughout the sample period.

Table 2: ICB industry composition of the STOXX 600

Sector	Number of Companies	Percentage
Basic Materials	51	6%
Consumer (D)	129	16%
Consumer (S)	58	7%
Energy	35	4%
Financials	143	17%
Health Care	74	9%
Industrials	170	21%
Real Estate	48	6%
Technology	51	6%
Telecommunications	35	4%
Utilities	33	4%
Total	**827**	**100%**

The sample is further subdivided into two groups: those subject to the EU ETS and those not. Data on ETS inclusion was collected from the sample firms' CDP reports, specifically their 2022 'Climate Change' submissions. In Section C11, 'Carbon Price', firms are required to disclose whether they are under any carbon pricing system (C11.1) and specify which carbon pricing regulation affects their operations (C11.1a) (CDP, n.d.). For the companies that did not participate in the CDP, the information about their inclusion/exclusion was gather through other publications such as their annual or sustainability reports.

Table 3: ETS subject and non-subject composition

Classification	Number of Companies	Percentage
ETS Subject	159	19%
ETS non-subject	668	81%
Total	**827**	**100%**

Additionally, Table 4 shows the percentage composition by sector of the 159 EU ETS subject firms in our sample.

Table 4: Industry composition of ETS subject and non-subject firms

Sector	ETS Subject	% of ETS Subject
Basic Materials	30	19%
Consumer (D)	20	13%
Consumer (S)	14	9%
Energy	17	11%
Financials	3	2%
Health Care	12	8%
Industrials	35	22%
Real Estate	3	2%
Technology	2	1%
Telecommunications	2	1%
Utilities	21	13%
Total	**159**	**100%**

For Hypothesis 3 the interaction term Cost of Emissions (COE) is included in our models. To create the variable, Scope 1 emissions were collected. Table 5 presents the number of firms with available Scope 1 emissions for our sample period.

Table 5: Industry composition of the companies that report on Scope 1 Emissions

Sector	Number of Companies	Percentage
Basic Materials	16	8%
Consumer (D)	20	11%
Consumer (S)	19	10%
Energy	9	5%
Financials	17	9%
Health Care	16	8%
Industrials	48	25%
Real Estate	8	4%
Technology	7	4%
Telecommunications	12	6%
Utilities	17	9%
Total	**189**	**100%**

4.2 Variables

This section presents the dependent, independent, and control variables used in our regression models. All variables are sourced on a monthly frequency throughout the sample period. To counteract the possibility of persistence due to some financial variables only being reported on an annual or semi-annual basis, all variables are annualized. Specifically, we annualized our data by taking the mean of the monthly values for each variable over 12 months. This approach ensures that our annualized values accurately reflect the average conditions throughout the year, rather than being influenced by end-of-year fluctuations.

4.2.1 Dependent Variable

For our dependent variable, Tobin's Q is used as a measure firm value. The definition of Tobin's Q is "the ratio of the market value of a firm to the replacement cost of its assets" (Chung & Pruitt, 1994, p. 70). Therefore, Tobin's Q is a comparison between the value assigned by the market to a firm and the total value of its assets. In addition, the modified version of Tobin's Q was used for this study, which consists of applying the natural logarithm. As expressed by Atanasova and Schwartz, 2019 and Amihud et al., 2018 using natural logarithm of Tobin's Q makes the data fit better as the datasets range is compressed, bringing extreme outliers closer to the mean. For clarity, the following formula used to calculate Tobin's Q is:

$$\text{Tobin's Q} = \ln\left(\frac{\text{Market Value} + \text{Total Debt}}{\text{Total Assets}}\right)$$

4.2.2 Independent variables

European Union Allowance – EUA price

As our main independent variable of interest, the EUA variable is the price of allowances from 01.01.2012 to 01.12.2022. The prices are obtained from the European Energy Exchange (EEX) and reflect the price of one ton of emissions of carbon dioxide (CO2), nitrous oxide (N2O) and/or perfluorocarbons (PFCs), as explained in chapter 1.2.2.

Fundamental Drivers Variable and Orthogonal EUA (EUA = EÛA + REUA)

To further study the impact of EUA prices on firm value, we decompose EUA prices into two components: a deterministic component explained by its fundamental drivers EÛA and an unexplained component REUA. The fundamental drivers are attained from:

- Oil prices: Europe Brent Spot Price Free on Board (Dollars Per Barrel)
- Energy prices: EEX Egix Trading Hub Europe Index Euro / Megawatt Hour
- Coal prices: HWWI Coal Europe
- Gas prices: Refinitiv Natural Gas Trading Hub Europe First Futures Month Euro Per Megawatt Hour

The basis for using these variables comes from Zhu et al., 2019, where oil, energy, coal, and gas prices are shown to be short- and long-term drivers of EUA prices. A regression is performed to assess the statistical relationship between the EUA and its fundamental drivers. The results are presented in Table 17 in the appendix. The model indicates that oil and coal prices are significant predictors of EUA prices, both being significant at the 1% level. Energy and gas prices are shown to only be marginally significant, both being significant at the 10% level.

EÛA

The EÛA represents the estimated values of EUA prices based on the regression of fundamental drivers. Including the EÛA variable in our model, alongside REUA, helps avoid the issue of perfect multicollinearity that would arise if REUA was included in models with EUA. The purpose of including this variable is to isolate and observe the impact of the deterministic component of EUA prices on firm value.

REUA

The residuals from this regression, representing the variation in EUA prices not explained by the energy related predictors, are used to create the orthogonal variable which is called REUA. REUA can therefore be seen as capturing the non-carbon related predictors of the EUA price. Including REUA in the regression models allows us to isolate the unexplained effect of EUA prices on Tobin's Q, removing the influence of the fundamental drivers.

These variables will be used in separate models for Hypothesis 1 to conduct a comparative analysis. This approach allows for determining if the influence of a carbon-related EUA estimate based on fundamental drivers is comparable to the effect of the overall EUA price on firm value.

Interaction Terms

Cost of emissions (COE)

This variable has been created to represent the direct costs of emitting, allowing us to further investigate the EU ETS impact on European firm value. EUA represents the price of allowances. Emissions represent the total Scope 1 emissions emitted by each firm measured in tons. We apply the natural logarithm to compress the data and reduce the range of observations. The interaction term is calculated as:

$$\text{COE} = \ln(\text{EUA} \times \text{Emissions})$$

EUA ETS Included

This interaction term represents the effect of the EUA price on EU ETS subject firms. It is calculated by multiplying the EUA price with a dummy variable that indicates whether a firm is part of the ETS or not, the distinction being obtained from the respective firms CDP reports. The dummy has values of 1 for ETS inclusion and 0 otherwise. For clarity, the term is calculated in the following way:

$$\text{EUA ETS Included} = (\text{EUA} \times \text{ETS Dummy})$$

COE ETS Included

This interaction term represents the effect of the cost of emissions on EU ETS subject firms. It is calculated in the same way as EUA_ETS_Included, by multiplying COE with a dummy variable that indicates whether a firm is part of the ETS or not, i.e. 1 for ETS inclusion and 0 otherwise. For clarity, the term is calculated in the following way:

$$\text{COE ETS Included} = (\text{COE} \times \text{ETS Dummy})$$

Control Variables

Based on the study made by Atanasova and Schwartz, 2019, Allayannis and Weston, 2001, Carter et al., 2006, Roll et al., 2010 and Bolton et al., 2011 it was decided to include the following control variables in our model as they have shown to affect firm value.

Dividend

Dividends is included as it may control for two scenarios that affect firm value. One is the idea that firms who pay dividends might have higher free cash flows and can therefore pursue positive NPV projects or overinvest in negative NPV projects, negatively affecting their firm value. Alternatively, paying dividends may result in capital constraints, resulting in a limited investment portfolio of only positive NPV projects, keeping their Q ratio high. As in the studies previously mentioned, the dividends ratio was calculated by dividing dividends paid by lagged total assets.

$$\frac{\text{Dividends}}{\text{Lagged Total Assets}}$$

Capital expenditure

Capital expenditure is included as a proxy for investment opportunities, as a firm's current and future value is dependent on its growth opportunities. Therefore, our variable represents investments that have been undertaken. As in the literature, we expect this variable to be positively associated with Tobin's Q. The variable is calculated by dividing capital expenditures by the lagged total assets:

$$\frac{\text{Capex}}{\text{Lagged Total Assets}}$$

Size

As in the aforementioned literature, Peltzman, 1977 provides broad evidence that a firm's size translates into operational efficiency, which can influence the market perception and thereby valuation. Size is calculated by applying natural logarithm to the total assets for the first month of every year:

$$\ln(Total\ Assets)$$

Profitability

By including profitability, we attempt to control for two scenarios. The first is that more profitable firms have access to better investment opportunities which could lead to higher Q ratios. The other is that high levels of cash flows could be an indicator of maturity and the stagnation of growth opportunities. Profitability is calculated by dividing a firms EBITDA by the lagged total assets.

$$\frac{\text{EBITDA}}{\text{Lagged Total Assets}}$$

Market Leverage

Capital structure is considered as it can influence firm value. Market leverage is calculated by dividing total debt by the sum of a firm's market capitalization and total debt:

$$\frac{Total\ Debt}{Market\ Value + Total\ Debt}$$

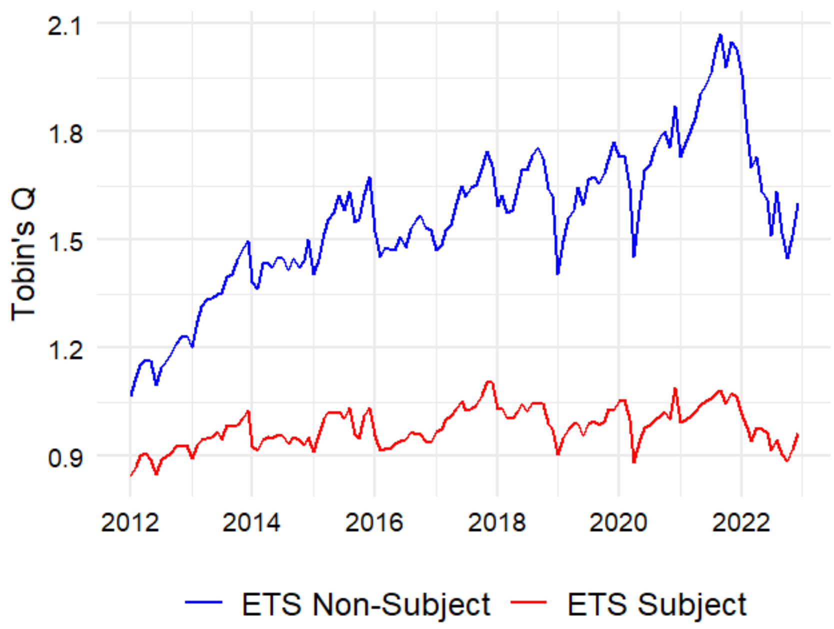
5 Descriptive Statistics

In this chapter, the descriptive statistics of our variables are presented. Descriptive statistics are used to summarize and describe the characteristics of our sample data, giving us a better understanding of its specific features. The two categories of measures used are central tendency and variability. The first includes measures of average or middle values such as mean and median. The second entails measures such as standard deviation, variance, range, skewness and kurtosis (Brooks, 2019).

5.1 Development of Time Series Data

This section describes the dynamic development of our dependent variable Tobin's Q, our main variable of interest EUA and our sample firms' Scope 1 emissions used to calculate COE. Specifically, we will illustrate their mean values and their general trend across our sample period.

Figure 1: Development of Tobin's Q



Notes: The vertical axis shows the average Tobin's Q of all the firms. The horizontal axis represents the sample period.

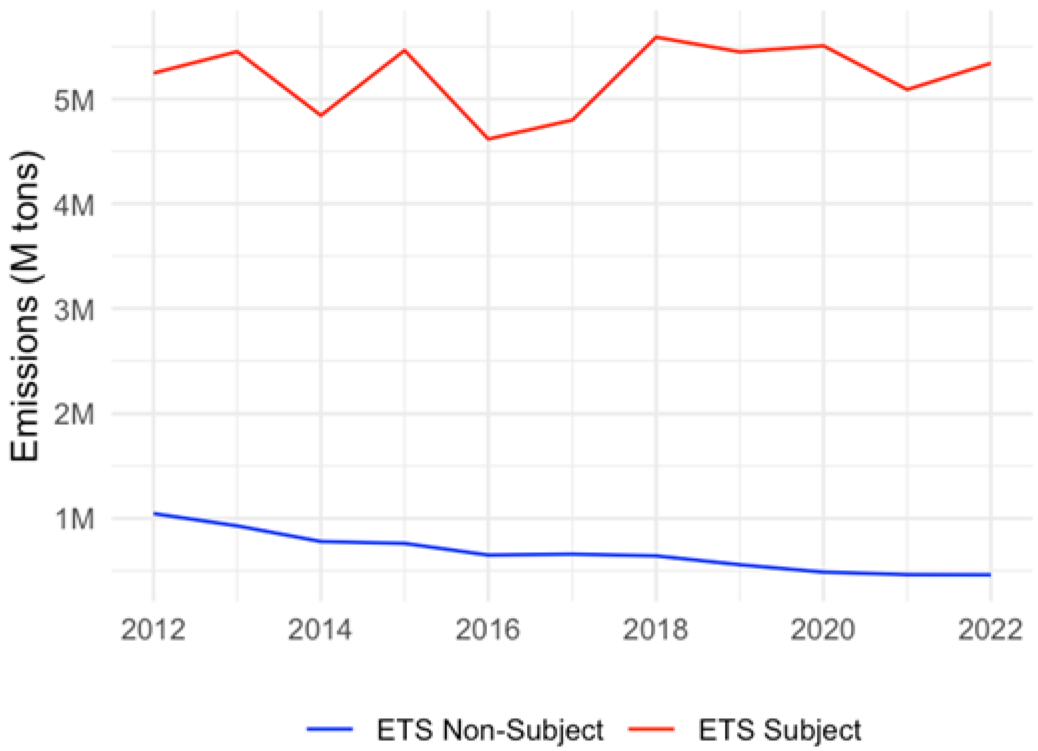
Figure 1 illustrates the changes of the mean firm value for ETS Subject and Non-Subject firms using non-logarithmically transformed Tobin's Q values, providing a clear visual representation of their trends. Non-subject firms have on average maximum (minimum) observed Tobin's Q ratios of 2.07 (1.07), while subject firms have ratios of 1.11 (0.85). Their mean Tobin's Q for the period is 1.56 and 0.97 respectively. This indicates a general positive market perception of STOXX 600 firms. Interestingly, Figure 1 also reveals that subject firms have a mean Tobin's Q 0.58 points lower than non-subject firms. This disparity is indicative of the sector composition of ETS subject firms as seen in Table 5, where mature and production-based sectors are predominantly represented, such as Industrials, Energy, Utilities, Basic Materials and Consumer(S)&(D).

Figure 2: EUA Price 2012-2022

Notes: The vertical axis shows the price of EUA in Euros and the horizontal axis reflects the years. The dotted vertical red lines are used to highlight the phases of the EU ETS and the introduction of the MSR.

Figure 2 displays the price of EUA from 2012 to 2022 with distinct markers for the introduction of the EU ETS Phase 3, 4 and the MSR. At first, consistent with the literature on the first two phases, the price remains relatively stable and low, reflecting the early inefficiencies of the system. Interestingly, post-2018 the EUA price starts to increase drastically. This could be due to the policy implementations in Phase 3 taking effect and the subsequent introduction of the MSR in 2019, aimed at reducing surplus allowances. After Phase 4, the price rises to a record €89.09. We interpret this as a combination of a more stringent system with a higher annual reduction rate and an expansion to cover more gases and sectors. These price dynamics could further be influenced by the geopolitical and economic change brought on by the 2019 Corona-pandemic and the onset of the Russo-Ukraine conflict in 2022, which was followed by shifts in European energy markets.

Figure 3: Scope 1 Emissions



Notes: The vertical axis shows the Scope 1 emissions measured in millions of tons, and the horizontal axis reflects the sample period.

Figure 3 illustrates the development of average Scope 1 emissions (in million tons) for ETS Subject and Non-Subject firms from 2012 to 2022. ETS Subject firms show an annual average increase of 0.383%. Interestingly, this indicates that emission volumes are on average increasing simultaneously with the reducing allowance cap of 1.76% and 2.2% for Phases 3 and 4. Conversely, average emissions for non-subject firms remain stable and low throughout the sample period, reducing on average by 5.09% annually.

5.2 Summary Statistics

Table 6 presents the summary statistics for the variables from our full dataset. The log transformed Tobin's Q has a negative mean of –0.08. The retransformed mean approximates to 0.92, suggesting that on average, firms' market values are roughly equivalent to their book value. However, the range from –7.99 to 4.27 and a standard deviation of 1.06 alludes to significant variation, with some firms having substantially low market to book values. This is further emphasized by the mean being more negative than the median and a negative skewness. Cumulatively, this suggests the presence of outliers pulling the mean downwards from the median. For EUA, the mean and median are 21.06 and 7.64 respectively, alluding to the 6–7

Table 6: Initial Summary Statistics

Variables	Observations	Mean	Median	St.Dev	Min	Max	Skew	Kurt
Tobin's Q	8450	-0.08	-0.03	1.06	-7.99	4.27	-0.85	3.62
EUA	11	21.06	7.64	22.94	4.52	80.05	1.60	1.34
EÛA	11	21.06	21.62	2.94	15.29	25.93	-0.36	-0.97
REUA	11	0.00	-0.16	2.03	-4.89	4.38	0.14	-0.39
Dividend	7791	1.04	0.44	2.45	0.00	69.29	12.32	236.76
CapEx	8237	0.08	0.03	3.82	0.00	346.46	90.69	8225.59
Size	8492	7.05	6.99	0.88	3.77	10.36	0.22	0.22
Market Leverage	7795	0.30	0.23	0.25	0.00	0.99	0.94	0.08
Profitability	8194	0.13	0.11	1.01	-1.66	90.36	86.74	7734.17

Notes: The table includes the descriptive statistics from all the variables before winsorizing

year period of relatively low EUA prices and the subsequent price rise post-2018. The discrepancy between the mean and median, along with a wide range from 4.52 to 80.05 and a standard deviation of 22.94, suggests to significant variability and a distribution heavily skewed towards higher prices in the latter part of the sample period. The positive skew and kurtosis can be attributed to regulatory impacts and structural shifts in the EUA price rather than random outliers.

EÛA has the same mean as EUA and a median of 21.62, suggesting a symmetrical distribution around its central values. However, its standard deviation of 2.94 points to moderate variability within a constrained range. The negative skew suggests more values below the mean. The mean and median for REUA are 0.00 and –0.16. The zero mean is expected as the variable is constructed using the residuals from an OLS regression, which sum to zero around the regression line. The range spans from –4.89 to 4.38, with a relatively high standard deviation of 2.03, suggesting substantial variability in the EUA's non-carbon related drivers. The skewness and kurtosis have relatively low values, indicating a close to normal distribution. The control variables exhibit relatively normal distribution values for their mean and median values. All variables show high positive skewness and kurtosis. These characteristics suggest a distribution with heavy tails and the presence of extreme outliers.

5.3 Dealing with Outliers

As described in the section above, some variables exhibit high levels of skewness and kurtosis. For clarity, skewness and kurtosis are defined as "the shape of the distribution and measures the extent to which it is not symmetric about its mean value" and kurtosis as "the fatness of the tails of the distribution and how peaked at the mean the series is". (Brooks, 2019, p. 101). All the variables are positively skewed in exception of Tobin's Q and EÛA, and the majority possess excess kurtosis. Specifically, Tobin's Q, Dividend, Capital Expenditure and Profitability. To address the presence of extreme outliers in the data a winsorizing process is applied at a 2% and 98% level. Winsorizing "is a procedure that moderates the influence of outliers on the mean and variance and thereby creates more robust estimators of location and variability" (Blaine, 2018, p. 1817). Essentially, the process compresses the data by adjusting the outlier towards a central value, thereby stabilizing the extreme impact on these calculations.

Table 7: Summary Statistics Post-Winsorizing

Variables	Observations	Mean	Median	St.Dev	Min	Max	Skew	Kurt
Tobin's Q	8450	-0.07	-0.03	0.97	-2.72	1.96	-0.50	0.55
EUA	11	21.06	7.64	22.94	4.52	80.05	1.60	1.34
EÛA	11	21.07	21.62	2.93	15.65	25.54	-0.36	-0.99
REUA	11	0.01	-0.16	2.00	-3.97	4.30	0.22	-0.53
Dividend	7791	0.91	0.44	1.31	0.00	6.26	2.29	5.60
CapEx	8237	0.04	0.03	0.04	0.00	0.16	1.46	2.04
Size	8492	7.05	6.99	0.84	5.39	8.99	0.23	-0.45
Market Leverage	7795	0.30	0.23	0.24	0.00	0.91	0.91	-0.02
Profitability	8194	0.12	0.11	0.10	-0.08	0.43	0.84	1.15

Notes: The table includes the descriptive statistics from all the variables after winsorizing

The mean and median of Tobin's Q are minimally more aligned at –0.07 and –0.03 or a retransformed value of approximately 0.93 and 0.97, indicating a slightly more symmetrical distribution around the central value and a slightly higher market to book ratio. This contrasts with the pre-refined data which exhibited a larger negative skew. Furthermore, the reduced range from -2.72 to 1.96 and standard deviation of 0.97 indicates less variability among the sample firms. In addition, the decreased kurtosis reflects the reduced prevalence of extreme outliers.

The EUA variable exhibits identical characteristics to the pre-winsorised variable, with the maximum value remaining at 80.05. EÛA and REUA show similar values to the pre-winsorised variables. As for the control variables, all variables show minimal reductions to their mean and median values, indicating their relative stability throughout the sample period. Dividend is the only variable which still contains high skewness and kurtosis, alluding to the persistence of extreme values in dividend distributions. Asides from Dividend, all control variables now exhibit a more normal, symmetric and less heavy-tailed distribution. Collectively, the post-winsorised characteristics of our data better represents variables central tendency and variability.

5.4 Correlation Matrix

Using the winsorised dataset, the correlation matrix represents the effects each variable have on one another . The variables positively correlated with Tobin's Q are EUA, Dividend, Capex and Profitability. EUA is shown to be minimally correlated with firm value (0.02), indicating the EUA price's limited direct impact

Table 8: Correlation Table with Numbered Variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tobin's Q	1								
EUA	0.02	1							
EÛA	0	0.01	1						
REUA	0	0.01	-0.16	1					
Dividend	0.21	0.33	0	0.01	1				
CapEx	0.27	-0.06	0	0	0.01	1			
Size	-0.59	0.07	0	0	-0.06	-0.18	1		
Market Leverage	-0.59	0.03	0	0	-0.13	-0.12	0.52	1	
Profitability	0.64	-0.01	0	0	0.13	0.36	-0.38	-0.5	1

Notes: This table shows the correlation between the variables. Where the numbers in the first row represent each variable in its respective order.

on European firm value, irrespective of their inclusion/exclusion to the EU ETS. Dividend (0.21) and Profitability (0.64) show moderate correlation with Tobin's Q, indicating that firms that with high profitability and consistent dividend payouts are generally valued higher than their respective book values. Capital Expenditure's (0.27) positive correlation indicates that the market valuation of firms is potentially rewarded for having undertaken investments, likely also being an indication of future growth opportunities. Conversely, Size (-0.59) and Market Leverage (-0.59) are negatively correlated with Tobin's Q, possibly reflecting that larger, more established firms, have lower market valuation relative to their book value and lower growth opportunities. Additionally, higher debt levels are associated with increased financial risk, depressing their firm value.

Regarding EUA, its correlation with the various control variables is low and to some degree negligible. Considering its influence on the more operational variables Dividend, Capital Expenditure and Profitability. This could be interpreted as the cost of the EUA is to some degree being considered, yet that these costs don't strongly influence their ability to distribute dividend, conduct investments or effect overall profitability. As for the more structural variables Size and Market Leverage, EUA does not seem to significantly correlate with either variable, suggesting that firms of different sizes and with varying capital structures are resilient to fluctuations in EUA prices. Overall, these findings could be related to the fact that only 19% of the sample firms are directly affected by EUA price movements, culminating in the lack of strong correlation between EUA and both operational and structural variables.

EÛA and REUA are shown to have no correlation with any of the control variables and exhibit low correlation with EUA and with each other. The control variables exhibit a moderate degree of correlation. Notably, Profitability and Dividend show a low but positive correlation (0.13), indicating that some profitable firms tend to distribute dividends. The same can be seen for Profitability and Capital Expenditure with a correlation (0.36), suggesting that profitable firms invest in growth opportunities. Size and Market Leverage are shown to be negatively correlated with the other control variables, yet strongly correlated with each other (0.52), this could allude to larger firms utilizing more leverage in their capital structures. Given the moderate correlation between some of our variables, the possible issue of multicollinearity arises.

Multicollinearity is defined as when explanatory variables are highly correlated with each other resulting in three possible issues. First, inflated R^2 values that misrepresent individual variables significance. Second, the regression model becomes sensitive to small changes. Third, confidence intervals may display wider parameters, resulting in misinterpreted significance levels (Brooks, 2019). To measure the extent of multicollinearity between our variables, we calculated their Variance Inflation Factors (VIF). VIF estimates measure to what extent the variance of a parameter estimates increases because the explanatory variables are correlated. In general, VIF values below 5 are acceptable and indicate no serious level of multicollinearity (Brooks, 2019). Table 9 shows none of our variables exceeding a VIF score of 1.627, meaning multicollinearity should not be an issue in our study.

Table 9: Variance Inflation Factor

Variables	VIF
EUA	1.128
Dividend	1.146
CapEx	1.162
Size	1.424
Market Leverage	1.627
Profitability	1.549

Notes: The table includes the results from the variance inflation factor test to assess the presence of multicollinearity.

6 Results

6.1 Model Building

To test the hypotheses, pooled OLS and fixed effects panel regressions were conducted. As described in section 3.3, the appropriate model was determined through a model specification test. The F tests for individual effects were consistently rejected across all models, specifically pooled OLS versus models with time and industry effects, indicating that fixed effects models enhance the explanatory power of our pooled model due to significant individual-specific variability. Additionally, it was relevant to test for the presence of heteroskedasticity and autocorrelation in the regressions. Both the Breusch-Pagan (BP) and Breusch-Godfrey (BG) tests indicated heteroskedasticity and serial correlation across all our regressions, as evident by the small p-values both tests produced. To address these issues, we employ the Arellano method to use robust standard errors (RSE). The method, as described by Arellano, 1987, controls for serial cross-sectional correlation and heteroskedasticity by applying heteroskedasticity and autocorrelation consistent (HC) standard errors. This method enhances the reliability of our results, although it does not directly solve for endogeneity that arises from other sources, such as omitted variables. Table 10 summarizes the model building process:

Table 10: Model Specification Tests

Hypothesis	Dependent Variable	Independent Variables	Individual Effects	BP (Het)	BG (Auto)	RSE
1	Tobin's Q	EUA	Reject H0	Reject H0	Reject H0	Yes
2	Tobin's Q	EUA	Reject H0	Reject H0	Reject H0	Yes
3	Tobin's Q	COE	Reject H0	Reject H0	Reject H0	Yes
4	Tobin's Q	Treatment-x-post	Reject H0	Reject H0	Reject H0	Yes

Notes: The table includes the results from the individual effects, Breusch-Pagan and Breusch-Godfrey tests for fixed effects significance, heteroskedasticity and serial correlation. If the null hypothesis is rejected then it is recommended to use robust standard errors (RSE) .

6.2 Empirical Results

To test the hypotheses presented in section 3.1 with the dependent, independent and control variables introduced in section 4.2, using the appropriate model chosen from 6.1, this section will present the results:

6.3 Hypothesis 1

"European firm value is negatively related to EUA prices".

$$
\begin{aligned}
\text{Tobin's Q}_{i,t} = \alpha_{i,t} + \beta_1 \text{EUA}_{i,t} + \beta_2 \text{Dividend}_{i,t} \\
+ \beta_3 \text{CapEx}_{i,t} + \beta_4 \text{Size}_{i,t} + \beta_5 \text{Profitability}_{i,t} \\
+ \beta_6 \text{MarketLeverage}_{i,t} + \lambda_i + \lambda_t + \mu_{i,t}
\end{aligned} \tag{1}
$$

Table 11: Regression Results for Hypothesis 1

	Dependent variable: Tobin's Q			
	Base Model	Time FE	Industry FE	Time + Industry FE
EUA	0.0009**	0.0024***	0.0003	0.0018***
	(0.0003)	(0.0004)	(0.0005)	(0.0004)
Dividend	0.0738***	0.0641***	0.0735***	0.0674***
	(0.0054)	(0.0061)	(0.0048)	(0.0144)
CapEx	1.3956***	1.4308***	-1.0397**	-1.0149**
	(0.2068)	(0.2061)	(0.2100)	(0.3888)
Size	-0.3576***	-0.3601***	-0.2544***	-0.2567***
	(0.0097)	(0.0097)	(0.0094)	(0.0239)
Market Leverage	-0.8263***	-0.8198***	-0.5746***	-0.5791***
	(0.0351)	(0.0351)	(0.0344)	(0.1035)
Profitability	3.5415***	3.5837***	3.2798***	3.3040***
	(0.0874)	(0.0874)	(0.2032)	(0.2050)
Constant	2.2466***	2.1163***	1.7724***	1.6627***
	(0.0692)	(0.0724)	(0.0671)	(0.1655)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	6,973	6,973	6,973	6,995
R^2	0.614	0.618	0.688	0.691
Adjusted R^2	0.613	0.617	0.687	0.690

Notes: This table presents the results from the regression models used to test Hypothesis 1. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted-R^2. All models employ a Pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models, respectively. The dependent variable is Tobin's Q. The main independent variable of interest is EUA ETS Included. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***.

The findings for Hypothesis 1 are presented in Table 11. The result indicates that the EUA price is statistically significant and positively associated with European firm value. Contrary to expectations of a negative relationship, the results indicate that 1 unit increase in EUA price is associated with a 0.0009% increase in European firm value, all else equal. One discrepancy is when controlling for industries, EUA is insignificant, possibly alluding to the sample composition of our dataset, where only 19% of firms are subject to the ETS. Nevertheless, we reject Hypothesis 1 as our results contradict our negative expectation.

All models exhibit relatively high adjusted R^2, ranging from 0.613 to 0.690.

Indicating that approximately 61% of the variability in European firm value can be explained by independent variables used in the models. These results align with the predictions from the literature, which highlight the selected control variables as significant predictors of firm value.

All control variables are significant at the 1% level across all models, except for Capex. The results for the Dividend indicate that a 1% increase in the ratio is associated with a 0.0738% increase in firm value. In line with our two scenarios for the variable, the result indicates that the market favourably rewards firms that manage a balance between the capital constraints induced by a dividend policy and the pursuit of positive NPV projects. For Capital Expenditure, a 1% increase in the ratio is associated with a 1.3956% increase in firm value. This result aligns with our expectations and reflects a favourable market perception of investment activities and growth opportunities. However, when controlling for industry fixed effects, the significance level drops to 5% and the coefficients sign becomes negative. This suggests that the impact of capital expenditure on firm value varies significantly across industries and that in certain industries, increased investment is negatively perceived.

Next, a 1% increase in the Profitability ratio is associated with a 3.5415% increase in firm value. This supports the scenario that the market favourably views more profitable firms, potentially due to their enhanced access to investment opportunities. Interestingly, the coefficient reduces when controlling for industries, suggesting that the impact of profitability on firm value varies across sectors. Market leverage and Size are the only coefficients negatively associated with firm value across all models. A 1% increase in market leverage is associated with a 0.8263% decrease in Tobin's Q, reflecting the perceived financial risk of increasing debt. This impact decreases when controlling for time and industry factors, suggesting that their characteristics moderates the negative effects. Lastly, the results for Size consistently show a negative association with Tobin's Q, indicating an additional increase in firm size is associated with a 0.3576% decrease in firm value. Regarding the expectation of size translating into operational efficiency, this result suggests larger firms may be perceived as less efficient or able to generate value in proportion to their size.

Hypothesis 1: "European firm value is negatively related to $\hat{EUA}$ prices".

$$\begin{aligned} \text{Tobin's } Q_{i,t} = & \alpha_{i,t} + \beta_1 \text{E}\hat{\text{U}}\text{A}_{i,t} + \beta_2 \text{REUA}_{i,t} + \beta_3 \text{Dividend}_{i,t} \\ & + \beta_4 \text{CapEx}_{i,t} + \beta_5 \text{Size}_{i,t} + \beta_6 \text{Profitability}_{i,t} \\ & + \beta_7 \text{MarketLeverage}_{i,t} + \lambda_i + \lambda_t + \mu_{i,t} \end{aligned} \tag{2}$$

Table 19 in the appendix presents the results for Hypothesis 1 with the decomposed EUA prices, specifically the deterministic component $\text{E}\hat{\text{U}}\text{A}$ and unexplained component REUA. Neither $\text{E}\hat{\text{U}}\text{A}$ nor REUA are statistically significant across any models. These results suggest that other factors than the carbon-related determinants and residual variation in EUA prices are more relevant in explaining variation in European firm value.

6.4 Hypothesis 2

"EU ETS subject firm value is negatively related to EUA prices".

$$\begin{aligned} \text{Tobin's } Q_{i,t} = & \alpha_{i,t} + \beta_1 \text{EUA}_{i,t} + \beta_2 \text{EUA\_ETS\_Included}_{i,t} \\ & + \beta_3 \text{Dividend}_{i,t} + \beta_4 \text{CapEx}_{i,t} \\ & + \beta_5 \text{Size}_{i,t} + \beta_6 \text{Profitability}_{i,t} + \beta_7 \text{MarketLeverage}_{i,t} \\ & + \lambda_i + \lambda_t + \mu_{i,t} \end{aligned} \tag{3}$$

Table 12 represents the results for Hypothesis 2. Like in Hypothesis 1, the results indicate that an increase in EUA prices has a positive effect on the general European market, even when controlling for whom is subject to regulatory compliance with the ETS. Conversely, for EU ETS subject firms, EUA prices are significant and negatively associated with firm value. This result is consistent across all models, indicating that a 1 unit increase in EUA prices is associated with a 0.0022% decrease in firm value, ceteris paribus. The effect becomes more pronounced when controlling for industries, possibly alluding to the sample composition of ETS subject firms where most scope 1 emission are concentrated. This could reflect the direct exposure these firms have to the cost of the ETS. Given these results, we fail to reject Hypothesis 2, suggesting that ETS subject firms are negatively effected by higher EUA prices.

Table 12: Regression Results for Hypothesis 2

	Dependent variable: Tobin's Q			
	Base Model	Time FE	Industry FE	Time + Industry FE
EUA	0.0014***	0.0029***	0.0012***	0.0027***
	(0.0004)	(0.0005)	(0.0004)	(0.0005)
EUA ETS Included	−0.0022**	−0.0022**	−0.0043***	−0.0043***
	(0.0009)	(0.0009)	(0.0008)	(0.0008)
Dividend	0.0724***	0.0625***	0.0718***	0.0658***
	(0.0130)	(0.0163)	(0.0115)	(0.0144)
CapEx	1.5504***	1.5884***	−0.9156**	−0.8775**
	(0.4088)	(0.4102)	(0.3836)	(0.3839)
Size	−0.3517***	−0.3542***	−0.2429***	−0.2463***
	(0.0300)	(0.0302)	(0.0239)	(0.0241)
Market Leverage	−0.8280***	−0.8213***	−0.5681***	−0.5583***
	(0.1038)	(0.1048)	(0.1021)	(0.1032)
Profitability	3.5496***	3.5916***	3.2822***	3.3134***
	(0.2331)	(0.2353)	(0.2017)	(0.2039)
Constant	2.1995***	2.0687***	1.6786***	1.5556***
	(0.1892)	(0.1874)	(0.1664)	(0.1660)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	6,956	6,956	6,956	6,956
R^2	0.6150	0.6190	0.6926	0.6957
Adjusted R^2	0.6146	0.6181	0.6918	0.6945

Notes: This table presents the results from the regression models used to test Hypothesis 2. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted-R^2. All models employ a Pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models, respectively. The dependent variable is Tobin's Q. The main independent variable of interest is EUA. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***.

These results tie into the mixed findings from the literature. The general positive effect on the market resonates with Jaraitė and Maria, 2016 findings where the ETS did not negatively effect firm profitability. Additionally, it ties in with Mo et al., 2012 and Veith et al., 2009 findings, where an ineffectual price and allowance distribution system in Phase 1 positively correlated with stock returns and firm value. Furthermore, when the market became more stringent in Phase 2, their results changed to the EUA price having a negative association. Our result may allude to the same stringent evolution, as the ETS is not effectual for our whole sample period, making the scheme profitable for some firms. It may also indicate that the general presence of a carbon market, where externalities are being priced, it positively reflects on the overall firm value of European firms, regardless of inclusion or exclusion to the scheme.

Turning to the negative correlation between the EUA price and ETS subject firms value. Our result coincides with the findings of Commins et al., 2011 and Yu, 2011 where ETS compliance costs negatively effect ROC and profit margins, thus potentially reducing Tobin's Q. Conversely, Aus Dem Moore et al., 2019 find that the ETS increased the asset base of subject firms, yet this increased investment may not immediately translate to an increase economic valuation as reflected in Tobin's Q, which is the case for our results. Lastly, considering Clarkson et al., 2015 findings where the scheme only negatively influences firm value when emissions surpass allocated allowances and costs cannot be passed on to consumers. The results could indicate that this scenario has become more prevalent, as the number of auctioned allowances has increased and the annually reducing cap could make it increasingly difficult for firms to absorb or pass on these costs.

Results for the control variables are similar to those in Hypothesis 1. Indicating that higher payouts, capital investments and higher profit margins are favourably viewed by the market, potentially being a signal of strong current financial health and future financial prospects, while increased leverage margins may allude to the opposite.

6.5 Hypothesis 3

"EU ETS subject firm value is negatively related to cost of emissions".

$$\begin{aligned}\text{Tobin's } Q_{i,t} = {} & \alpha_{i,t} + \beta_1 \text{COE}_{i,t} + \beta_2 \text{COE\_ETS\_Included}_{i,t} \\ & + \beta_3 \text{Dividend}_{i,t} + \beta_4 \text{CapEx}_{i,t} \\ & + \beta_5 \text{Size}_{i,t} + \beta_6 \text{Profitability}_{i,t} + \beta_7 \text{MarketLeverage}_{i,t} \\ & + \lambda_i + \lambda_t + \mu_{i,t}\end{aligned} \tag{4}$$

Table 13 summarizes the results for the Hypothesis 3. In the base model, the coefficient COE is positive and significant at the 10% level, suggesting an additional 1% increase in the cost of emissions is associated with a 0.0134% increase in firm value, ceteris paribus. This result is consistent with the general positive effect of EUA prices in the two previous hypotheses. Conversely, when controlling for industry fixed effects, COE becomes negative and significant at the 1% level. This result underscores the heterogeneity of emissions costs across industries, where the concentration of emissions costs in some industries could exhibit a higher financial burden. Turning to COE ETS Included, the coefficients are consistently negative across all four models, yet is only statistically significant at the 10% when controlling for industry fixed effect. This result coincides with the negative significance for COE when controlling for industry, suggesting consistency regarding emissions costs having a negative impact on firm value, regardless of subjugation to the system. Given these results, we fail to reject Hypothesis 3, but only when controlling for Industry fixed effects.

Table 13: Regression Results for Hypothesis 3

	Dependent variable: Tobin's Q			
	Base Model	Time FE	Industry FE	Time + Industry FE
COE	0.0134*	0.0128	−0.0362***	−0.0407***
	(0.0076)	(0.0079)	(0.0083)	(0.0090)
COE ETS Included	−0.0043	−0.0041	−0.0042*	−0.0036
	(0.0027)	(0.0027)	(0.0023)	(0.0024)
Dividend	0.0602***	0.0564***	0.0615***	0.0523***
	(0.0127)	(0.0166)	(0.0116)	(0.0148)
CapEx	1.1301**	1.1940***	−0.4847	−0.3591
	(0.4456)	(0.4500)	(0.4322)	(0.4353)
Size	−0.3539***	−0.3515***	−0.1934***	−0.1881***
	(0.0364)	(0.0365)	(0.0304)	(0.0308)
Market Leverage	−0.8870***	−0.8855***	−0.4867***	−0.4794***
	(0.1104)	(0.1116)	(0.1126)	(0.1138)
Profitability	3.5660***	3.6068***	3.2564***	3.2906***
	(0.2418)	(0.2438)	(0.2063)	(0.2075)
Constant	2.1336***	2.0254***	1.8308***	1.7185***
	(0.2023)	(0.2000)	(0.1874)	(0.1860)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	5,604	5,604	5,604	5,604
R^2	0.6242	0.6271	0.7071	0.7104
Adjusted R^2	0.6237	0.6260	0.7063	0.7090

Notes: This table presents the results for the regression models used to test Hypothesis 3. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted-R^2. All models employ a Pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models, respectively. The dependent variable is Tobin's Q. The main independent variable of interest is COE ETS Included. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***.

The consistently negative effect of COE and COE ETS Included when controlling for industry fixed effects can be understood by assessing the sample composition, development of emissions and the literature. ETS non-subject firms comprise 81% of the sample, with average emissions volumes below 1 million tons throughout the period. Despite this low average, the market wide composition may include high polluting industries exempt from the ETS, potentially leading to the negative connotation with our emissions cost proxy. This might suggest a scenario where many industries are highly exposed to transitional risk by future inclusion in the ETS. These results are in line with the findings of Matsumura et al., 2014 and Perdichizzi et al., 2024 where the market penalizes firms based on the amount of their carbon emissions. Furthermore, they also resonate with the findings of Delis et al., 2019 and Atanasova and Schwartz, 2019, where owning and investing in carbon related assets negatively impacts firm value, especially when firms are located more stringently regulated regions. The findings in Hypothesis 3 and those of the literature mentioned, support the notion of markets increasingly sensitive assessment of carbon related assets and its adverse effect on firm value.

Parallel Trends Assumption

As explained in section 3.4.2, verifying the parallel trends assumption is a critical prerequisite for obtaining valid results in the DiD analysis. Specifically, validating the assumption ensures that with the absence of the treatment, the two groups would have continued to follow a similar trend over time. To conduct the test, we created a "Time Trend" variable that captures the annual growth of Tobin's Q. Then, as with the variable EUA ETS Included, we differentiate between subject and non-subject firms using the ETS dummy, creating the interaction term "Time Trend X Treatment". This variable allows for observing whether the growth rates between the treatment and control group significantly differ over time pre-2019. For clarity, if the interaction term is significant, then there is a significant difference between the two groups trends, and the assumption is violated, making our DiD results biased. The fixed effects regression model for the parallel assumptions is:

$$\text{Tobin's Q}_{i,t} = \alpha_{i,t} + \beta_1 \text{Time Trend}_{ETSi,t} + \lambda_i + \lambda_t + \mu_{i,t}$$

Robust standard errors identical to those presented in section 6.1 were applied. Results for the parallel trend assumption are presented in Table 21 in the appendix, accompanied by a graphical representation in Figure 4. The "Time Trend" coefficient varies in size but is positive and significant at the 1% level across all four models, indicating a 4.2% average annual growth rate in Tobin's Q across all firms from 2012 to 2018. The interaction term "Time Trend x Treatment" has a negative and significant coefficient at the 10% level in the base model and when controlling for time fixed effects. This significant coefficient suggests slightly differential trends between the treatment and control group, potentially making our results biased. However, when controlling for industry fixed effects, the coefficient becomes insignificant, indicating that the differential trends are due to industry-specific factors. This finding suggests that the treatment effect is more accurately estimated when accounting for industry-specific factors, supporting the validity of our results when industry controls are applied. Keeping the possibility of biased results in mind, we proceed with testing Hypothesis 4.

6.6 Hypothesis 4

"The EU ETS subject firm value has had a differential and negative trend to non-subject firms following the introduction of the Market Stability Reserve".

$$
\begin{aligned}
\text{Tobin's Q}_{i,t} = &\alpha_{i,t} + \beta_1 \text{Treatment}_{i,t} + \beta_2 \text{Post}_t + \beta_3 (\text{Treatment}_{i,t} \times \text{Post}_t) \\
&+ \beta_4 \text{EUA}_{i,t} + \beta_5 \text{Dividend}_{i,t} \\
&+ \beta_6 \text{CapEx}_{i,t} + \beta_7 \text{Size}_{i,t} + \beta_8 \text{Profitability}_{i,t} \\
&+ \beta_9 \text{MarketLeverage}_{i,t} + \mu_{i,t}
\end{aligned} \tag{5}
$$

Table 14: Difference in Difference Regression Results for EUA

	Dependent variable: Tobin's Q			
	Base Model	Time FE	Industry FE	Time + Industry FE
Treatment	0.0319	0.0336	-0.1126**	-0.1109**
	(0.0402)	(0.0403)	(0.0372)	(0.0372)
Post Treatment	0.1197***	0.2776***	0.0747***	0.2460***
	(0.0208)	(0.04994)	(0.0205)	(0.0582)
Treatment X Post	-0.1241***	-0.1261***	-0.0908**	-0.0925**
	(0.0313)	(0.0321)	(0.0302)	(0.0294)
EUA	-0.0004	-0.0010*	-0.0006*	-0.0014**
	(0.0004)	(0.0004)	(0.0003)	(0.0005)
Dividend	0.0671***	0.0628***	0.0687***	0.0662***
	(0.0135)	(0.0163)	(0.0122)	(0.0143)
CapEx	1.4958***	1.5059***	-0.8528***	-0.8381***
	(0.4100)	(0.4112)	(0.2101)	(0.2095)
Size	-0.3549***	-0.3580***	-0.2378***	-0.2405***
	(0.0306)	(0.0308)	(0.0244)	(0.0245)
Market Leverage	-0.8331***	-0.8196***	-0.5716***	-0.5568***
	(0.1046)	(0.1051)	(0.1020)	(0.1031)
Profitability	3.5647***	3.5948***	3.2559***	3.2778***
	(0.2346)	(0.2376)	(0.0799)	(0.2052)
Constant	2.2158***	2.1145***	1.6598***	1.5619***
	(0.1906)	(0.1896)	(0.1683)	(0.1683)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	6,956	6,956	6,956	6,956
R^2	0.6158	0.6187	0.6937	0.6959
Adjusted R^2	0.6153	0.6179	0.6924	0.6947

Notes: This table presents the results of the DiD regression models used to test Hypothesis 4. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted R^2. All models employ a pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models. The dependent variable is Tobin's Q. The main independent variable of interest is Treatment X Post. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***, respectively.

The results from the DiD model are shown in Table 14. The positive and significant "Post Treatment" variable indicates that following the introduction of the MSR in 2019, there was a general positive improvement in Tobin's Q. Specifically, the base model shows an average increase in firm value of 11.97%. When controlling for time fixed effects, the coefficient displays a significant increase, suggesting a positive surge in market perception and firm value in the years following 2019. When controlling for industry, the variable indicates less growth. These results align with the trends observed in Figure 4 and suggest that the overall European market experienced an appreciation in firm value post-2019.

However, the "Treatment X Post" variable, which has a negative and significant coefficient at the 1% to 5% levels across all models, indicates that post-MSR, ETS subject firms experienced a relative decrease in firm value compared to the control group. Specifically, the treatment group experienced an average decrease in firm value ranging from 12% to 9%. This result suggests that although market conditions generally improved, the specific introduction of the MSR confounded in a 12% average decrease in EU ETS subject firm value.

Our findings support Hypothesis 4, indicate that the firm value of EU ETS subject firms is negatively affected by the implementation of the MSR. More broadly, viewing the MSR and the period around 2019 as a proxy for improved ETS market mechanisms and a more efficient scheme, this analysis aligns with our previous findings and reinforces the notion that a more stringent ETS negatively affects the value of subject firms.

7 Robustness Tests

For the robustness tests, we substitute EUA prices with EUA Volatility. The new variable of interest EUAVOL is created by taking the standard deviation of monthly returns of the EUA price grouped by their corresponding year, then the average of the corresponding 12-month period is made to fit our datasets frequency. In addition, an interaction term called EUA ETS Included Vol, calculated as EUAVOL multiplied by the ETS dummy.

7.1 Hypothesis 1

"European firm value is negatively related to EUA prices volatility".

$$\begin{aligned}\text{Tobin's Q}_{i,t} = {} & \alpha_{i,t} + \beta_1 \text{EUAVOL}_{i,t} + \beta_2 \text{Dividend}_{i,t} + \beta_3 \text{CapEx}_{i,t} + \beta_4 \text{Size}_{i,t} \\ & + \beta_5 \text{Profitability}_{i,t} + \beta_6 \text{Market Leverage}_{i,t} \\ & + \lambda_i + \lambda_t + \mu_{i,t}\end{aligned} \tag{6}$$

Table 15: Regression Results for Hypothesis 1

	Dependent variable: Tobin's Q			
	Base Model	Time FE	Industry FE	Time + Industry FE
EUAVOL	−0.4898***	−2.7875***	−0.4887***	−2.0673***
	(0.0757)	(0.5546)	(0.0702)	(0.4887)
Dividend	0.0775***	0.0635***	0.0735***	0.0674***
	(0.0121)	(0.0163)	(0.0108)	(0.0144)
CapEx	1.3371***	1.3978***	−1.0627***	−1.0149***
	(0.4116)	(0.4141)	(0.3882)	(0.3888)
Size	−0.3567***	−0.3596***	−0.2542***	−0.2567***
	(0.0293)	(0.0296)	(0.0237)	(0.0239)
Market Leverage	−0.8265***	−0.8263***	−0.5753***	−0.5710***
	(0.1033)	(0.1045)	(0.1021)	(0.1035)
Profitability	3.5403***	3.5860***	3.2690***	3.3040***
	(0.2328)	(0.2350)	(0.2028)	(0.2050)
Constant	2.3286***	2.6684***	1.8648***	2.0721***
	(0.1893)	(0.2320)	(0.1675)	(0.1979)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	9097	9097	9097	9097
R^2	0.6132	0.6171	0.6890	0.6914
Adjusted R^2	0.6129	0.6163	0.6882	0.6903

Notes: This table presents the results of the robustness tests for Hypothesis 1. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted R^2. All models employ a pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models. The dependent variable is Tobin's Q. The main independent variable of interest is EUAVOL. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***, respectively.

Table 15 indicates that the volatility of EUA prices has a significant and negative effect on firm value across all models, in contrast to the results from Hypothesis 1. The Base model coefficient indicates that a 1% increase in the volatility of EUA prices is associated with an average decrease of 0.4898% in firm value, ceteris paribus. These findings suggest that high volatility in EUA prices is a stronger and more negative determinant of firm value than price rises themselves, as evident when comparing to the results of Hypothesis 1. The development of the EUA Prices from Figure 2 can aid in understanding these results, where periods of pronounced volatility post 2018 are visible and may necessitate unexpected buying or selling of allowances, diminishing their firm valuation. As for the control variables, the results are in line with those from Hypothesis 1, affirming their robustness. The only contradiction is capital expenditure, which exabits a more negative and significant coefficient, possibly alluding to increased risk of investments under volatile ETS conditions.

7.1.1 Robustness Test - Fundamental Drivers Analysis

Hypothesis 1 “European firm value is negatively related to $\widehat{\text{EUA}}$ price volatility”

$$\begin{aligned}\text{Tobin's Q}_{i,t} = \alpha_{i,t} &+ \beta_1 \widehat{\text{EUAVOL}}_{i,t} + \beta_2 \text{REUAVOL}_{i,t} + \beta_3 \text{Dividend}_{i,t} \\ &+ \beta_4 \text{CapEx}_{i,t} + \beta_5 \text{Size}_{i,t} + \beta_6 \text{Profitability}_{i,t} \\ &+ \beta_7 \text{MarketLeverage}_{i,t} + \lambda_i + \lambda_t + \mu_{i,t}\end{aligned} \tag{7}$$

Table 20 presents the results for the robustness test using the $\widehat{\text{EUAVOL}}$ and REUAVOL. The results indicate that when we use the estimated values of EUAVOL as a determinant of the fundamental drivers, the effect on Tobin’s Q intensifies resulting in the highest coefficient estimates across all the models in this study. When adding time fixed effects, $\widehat{\text{EUAVOL}}$ increases substantially. Interestingly, REUA is also positive and significant when controlling for time fixed effects, indicating that factors other than the carbon related drivers have an effect on Tobin’s Q. These results significantly contrast those found in the fundamental driver’s analysis results for Hypothesis 1.

The sizable estimated coefficients observed in the $\widehat{\text{EUAVOL}}$ model require further investigation due to the considerable impact and difference with the other models in this study. The results may suggest that the fundamental drivers of EUAVOL, namely oil, gas, coal and energy prices are inherently volatile themselves and alludes to an interconnectedness not fully investigated in our research. There is also a possibility of measurement error for $\widehat{\text{EUAVOL}}$.

7.2 Hypothesis 2

"EU ETS subject firm value is negatively related to EUA price volatility"

$$
\begin{aligned}
\text{Tobin's } Q_{i,t} = & \alpha_{i,t} + \beta_1 \text{EUAVOL}_{i,t} + \beta_2 \text{EUAVOL\_ETS\_Included}_{i,t} \\
& + \beta_3 \text{Dividend}_{i,t} + \beta_4 \text{CapEx}_{i,t} + \beta_5 \text{Size}_{i,t} \\
& + \beta_6 \text{Profitability}_{i,t} + \beta_7 \text{Market Leverage}_{i,t} \\
& + \lambda_i + \lambda_t + \mu_{i,t}
\end{aligned}
\tag{8}
$$

Table 16: Regression Results for Hypothesis 2

	Dependent variable: Tobin's Q			
	Base	Time FE	Industry FE	Time + Industry FE
EUAVOL	−0.4821***	−2.8035***	−0.2944***	−1.8420***
	(0.0952)	(0.5640)	(0.0878)	(0.4958)
EUAVOL ETS Included	−0.0626	−0.0595	−0.9051***	−0.8954***
	(0.2474)	(0.2484)	(0.2251)	(0.2259)
Dividend	0.0771***	0.0630***	0.0723***	0.0666***
	(0.0121)	(0.0163)	(0.0107)	(0.0144)
CapEx	1.3745***	1.4343***	−0.9484**	−0.9031**
	(0.4089)	(0.4111)	(0.3848)	(0.3849)
Size	−0.3553***	−0.3583***	−0.2391***	−0.2418***
	(0.0304)	(0.0307)	(0.0242)	(0.0244)
Market Leverage	−0.8250***	−0.8244***	−0.5655***	−0.5607***
	(0.1038)	(0.1049)	(0.1015)	(0.1029)
Profitability	3.5496***	3.5949***	3.2435***	3.2775***
	(0.2351)	(0.2374)	(0.2030)	(0.2053)
Constant	2.3170***	2.6622***	1.7480***	1.9510***
	(0.1956)	(0.2386)	(0.1716)	(0.2027)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	9097	9097	9097	9097
R^2	0.6136	0.6175	0.6923	0.6947
Adjusted R^2	0.6132	0.6166	0.6915	0.6935

Notes: This table presents the results of the robustness test of the regression models used to test hypothesis 2. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted R^2. All models employ a Pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models. The dependent variable is Tobin's Q. The main independent variable of interest is EUAVOL ETS Included. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***, respectively.

Table 16 presents the results for the robustness test of Hypothesis 2. The coefficients for EUAVOL are negative and significant across all models, in line with the previous test. This indicates a negative relation to the volatility of EUA prices on European firm value, even when controlling for whom is subject to the scheme. The variable of interest EUAVOL ETS Included is only significant when controlling for industries fixed effects and both time and industries fixed effects, thereby being inconsistent with the results from Hypothesis 2. The results suggest that when controlling for industry fixed effects, a 1% increase in the volatility of EUA prices is associated with an average decrease in firm value of 0.9051% for subject firms, ceteris paribus. This indicates that the volatility of EUA prices has a more pronounced negative effect than variations EUA prices for subject firms. This finding underscores the importance of a well-functioning market mechanism, where unpredictable price volatility can pose a substantial financial strain and negative effect on subject firms value.

8 Discussion

As mentioned in chapters 1 and 2, the goal of our research is not limited by the relation of the EU ETS and subject companies' firm value but extends to seeing this relationship considering the potential for asset stranding. Beginning with a broad categorization of our sample, all firms are exposed to transitional risk, environmentally related or not. Given the context of the literature, the subject firms are specifically exposed to an increasingly stringent and evolving allowance cap-and-trade system and changing public sentiment. Moreover, as a prerequisite for their inclusion in the ETS, these firms are directly or indirectly subject to the plausible but theoretical concepts of unburnable carbon and a carbon bubble, where their carbon related assets value could be overinflated and become prematurely devalued as Europe transitions to cleaner energy sources.

The results from Hypothesis 2 show a negative association between EUA prices and the firm value of ETS subject firms, highlighting the direct financial impact of increased regulatory costs induced by the ETS. This result is compounded by the results from Hypothesis 3, where the direct costs of emissions is negatively associated with both subject and non-subject firms. In addition, the results from Hypothesis 4 suggest an overall downward trend in growth of subject firms following a more stringent ETS post-2019. Cumulatively, these results highlight the potential depreciation of assets heavily tied to carbon related policies and emission levels, suggesting the existence or formation of a carbon bubble and the presence of transitional risk. Turning to unburnable carbon, subject firms could be exposed to this concept as industrial, utilities, basic materials and energy firms' assets and inherent infrastructure are tied to the use of carbon related commodities and thereby also their discontinued use. This suggests a costly transition is needed to meet the EUs emission reduction targets presented in the introduction.

The findings from the robustness test on EUAVOL and $EUA\hat{V}OL$ exacerbate the transitional risk faced by subject and non-subject firms. The significant negative association of EUA price volatility on firm value reflects the uncertain financial burden of firms heavily reliant on trading allowances to mirror their emissions. The more pronounced results indicate that the market perception of a firm's future financial stability is negatively influenced by unanticipated fluctuations in allowances prices, which is already a reality when observing the development of EUA prices, further intensifying the risk of asset stranding.

Connecting our findings to the literature on stranded assets. Our research lacks a specific measurable variable for asset stranding as with Delis et al., 2019 and Atanasova and Schwartz, 2019, who create variables to assess the possibility of assets stranding, namely interest rates on syndicate loans for fossil fuel firms and growth in undeveloped oil reserves. However, our results align with the broader trends observed in their research. Similar is the finding of carbon related firm value being adversely impacted by market sentiment. Additionally, assuming European climate policy and the evolution of the ETS is relatively more stringent than other regulatory regions in the world, our findings mirror their observations when considering pronounced negative effect in geographic areas with more stringent regulations. Our results, though not definitive, suggest that as the ETS intensifies, the risk of asset stranding increases for GHG intensive sectors.

9 Further Research and Limitations

Across the development of this study some limitations arose. First, only 189 out of the 827 companies in our sample had Scope 1 emissions data. This limitation complicates our efforts of having results that are representative for the whole market. Additionally, discrepancies in financial data produced by Datastream were found. Notably in the pre-winsorised maximum values of Dividends and Capital Expenditure, values that realistically should range from 0 to 1, had values of 69.29 and 346.46. This indicates to the potential of measurement error. Another challenge was identifying ETS subject firms, as a small number of firms did not participate in the CDPs annual climate change reports. This forced us to rely on inconclusive information from annual and sustainability reports, possibly leading to classification errors that could effect our results. Lastly, we found a limited amount of literature on the specific topic of firm value within the context of the EU ETS. To the best of our knowledge Clarkson et al., 2015 is one of only few research articles that specifically addresses emissions and firms value accounting for the use of the EU ETS allowances.

Throughout this study it was found that there are still many unexplored opportunities to analyse the effectiveness of the EU ETS and its impact on subject firms. For further research, our recommendations would be to conduct additional analysis using the volatility of EUA prices rather than prices themselves, as it seemed to better capture the relationship between the EU ETS and firm value. We also recommend to further investigate specific industries, to observe in detail which subject industries are more affected by the EU ETS, and which show signs of adapting to carbon related policies. Lastly, it would be of interest to expand the scope of this study by analysing and comparing other geographic regions with allowance cap and trade systems.

10 Conclusion

As nations globally confront the realities of an escalating climate crisis, the pursuit of effective emissions reduction policies has become paramount. To address this challenge, the international community has configured frameworks like the KP and PA that have assigned regional and national emission reduction targets. The EU has emerged as a leader in this initiative by implementing the EU ETS, which is now the largest and most enduring allowance cap-and-trade system in the world. Previous literature mostly concentrated on the initial two phases of the system, providing mixed and sometimes contradicting results, reflecting the difficult process of establishing well-functioning market mechanisms from inception. This thesis builds on previous findings by cross-sectionally examining the EU ETS over three of its four phases, offering insight into the system's effect on European firm value as its structure and market mechanism become more effective, mirroring the emission reduction targets it was designed to help meet

The results indicate a consistent narrative regarding the relationship between EUA prices and firm value. Aside from the initial positive association between EUA prices and the general market, EUA prices and subject firms value show a consistently negative association. This trend is evident across various facets of EUA prices, including direct emissions costs, EUA price volatility, and the negative growth trends of subject firms following the implementation of more stringent market regulations. These findings align more with the literature on the relation between firm value, emissions costs and carbon related assets, rather than the mixed outcomes from the EU ETS literature.

In theory, an allowance cap-and-trade system should not inherently have a negative effect on firm value as it allows for emission allowances to be allocated efficiently where the marginal cost of abatement equals the marginal benefit of emissions. Thereby, the systems primary aim is to reduce emissions, not penalize firms financially. However, this study suggests that both subject and non-subject firms experience negative effects related to the pricing and cost of emissions. This indicates a potential shortfall in industries ability to abate, adapt or mitigate their emission producing activities as the ETS becomes more stringent.

Lastly, the findings bring up the critical issue of stranded assets in the face of tightening environmental regulations. As financial markets and investors evaluate the future valuation of subject firms, particularly those with carbon related assets and investments, a more stringent ETS and an annually reducing emissions cap could emerge as significant factors to consider. The consistently negative effect of EUA prices on firm value could place subject firms with a double disadvantage, a decrease in firm valuation coupled with escalating costs, increasing the risk of asset stranding. However, this study suggests that this challenge is not solely confined to subject firms. The negative correlation between emissions costs and the firm value of the wider European market could suggest many industries are vulnerable to transitional risk by future inclusion in the ETS or the implementation of similar carbon taxes. These dynamics underscore the necessity for industries to holistically plan their emissions reduction activities and for regulators to develop policy frameworks in conjunction with the ETS to support transitional strategies that mitigate the adverse financial impacts of environmental compliance.

The findings in this thesis give insight on the relatively understudied latter phases of the EU ETS and its impact on the value of subject firms. Thereby, it should be of interest to a broad range of entitles, ranging from policymakers and environmental regulators to investors and corporate managers. Ultimately, it highlights the financial risks associated with emissions related policies for subject firms and those potentially subject in the future, and the need to facilitate an economically sustainable transition towards a low-carbon economy.

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Appendices

A Tables

Table 17: EUA Regression Results

	Dependent variable:
	EUA
OIL	-0.133^{***}
	(0.047)
ENE	-0.711^{*}
	(0.414)
GAS	0.757^{*}
	(0.389)
COAL	0.137^{***}
	(0.026)
Constant	6.339
	(3.911)
Observations	132
R^2	0.682
Adjusted R^2	0.672
Residual Std. Error	13.454 (df = 127)
F Statistic	68.243^{***} (df = 4; 127)

Notes: This table presents the results of the EUA fundamental drivers regression model. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted R^2. The model employs an OLS regression. The dependent variable is EUA. The independent variables are the fundamental drivers of EUA prices. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***, respectively.

Table 18: Correlation Table with EUAVOL

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Tobin's Q	1						
EUAVOL	-0.03	1					
Dividend	0.14	-0.06	1				
CapEx	0	0	0	1			
Size	-0.58	-0.02	-0.04	0	1		
Market Leverage	-0.57	0.02	-0.09	0.03	0.53	1	
Profitability	0.06	-0.01	0.01	0.99	-0.03	-0.02	1

Notes: The table shows the correlation between the variables used for the robustness tests.

Table 19: Hypothesis 1 with $\hat{EUA}$

	Dependent variable: Tobin's Q				
	Base Model (2a)	Base Model (2b)	Time FE	Industry FE	T + I FE
$\hat{EUA}$	-0.0008	-0.0008	-0.0007	-0.0004	-0.0003
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)
REUA		-0.0006	0.0001	0.0003	0.0004
		(0.0004)	(0.0003)	(0.0003)	(0.0003)
Dividend	0.0793***	0.0793***	0.0641***	0.0735***	0.0678***
	(0.0123)	(0.0121)	(0.0163)	(0.0108)	(0.0145)
CapEx	1.3687***	1.3687***	1.4307***	-1.0397**	-1.0149**
	(0.2067)	(0.2067)	(0.4137)	(0.2100)	(0.3888)
Size	-0.3576***	-0.3576***	-0.3609***	-0.2544***	-0.2573***
	(0.0097)	(0.0097)	(0.0296)	(0.0094)	(0.0239)
Market Leverage	-0.8235***	-0.8235***	-0.8199***	-0.5746***	-0.5652***
	(0.0352)	(0.0352)	(0.1042)	(0.0344)	(0.1037)
Profitability	3.5415***	3.5415***	3.5831***	3.2798***	3.3109***
	(0.0875)	(0.0875)	(0.2352)	(0.2032)	(0.2054)
Constant	2.2657***	2.2656***	2.1492***	1.7724***	1.6688***
	(0.0833)	(0.0837)	(0.1884)	(0.0671)	(0.1686)
Year dummies	No	No	Yes	No	Yes
Industry dummies	No	No	No	Yes	Yes
Observations	6,973	6,973	6,973	6,973	6,973
R^2	0.613	0.613	0.618	0.688	0.691
Adjusted R^2	0.613	0.612	0.617	0.687	0.690

Notes: This table presents the results of the fundamental drivers regression models used to test hypothesis 1. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted R^2. All models employ a pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models. The dependent variable is Tobin's Q. The main independent variable of interest is $\hat{EUA}$. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***, respectively.

Table 20: Robustness Test for Hypothesis 1 with $\widehat{EUAVOL}$

	Dependent variable: Tobin's Q				
	Base Model (2a)	Base Model (2b)	Time FE	Industry FE	T + I FE
$\widehat{EUAVOL}$	-11.5830***	-11.5783***	-44.9854***	-10.3756***	-36.2051***
	(1.6688)	(1.6698)	(6.8813)	(1.5331)	(7.3401)
REUAVOL		0.1171	10.6729**	-0.3744	4.3321
		(0.3954)	(5.1502)	(0.3816)	(4.2370)
Dividend	0.0744***	0.0744***	0.0641***	0.0707***	0.0678***
	(0.0123)	(0.0123)	(0.0123)	(0.0109)	(0.0145)
CapEx	1.3775***	1.3777***	1.4308***	-1.0371***	-1.0035***
	(0.4109)	(0.4109)	(0.4137)	(0.3874)	(0.3883)
Size	-0.3576***	-0.3576***	-0.3601***	-0.2557***	-0.2577***
	(0.0293)	(0.0293)	(0.0293)	(0.0237)	(0.0239)
Market Leverage	-0.8183***	-0.8183***	-0.8198***	-0.5682***	-0.5651***
	(0.1038)	(0.1034)	(0.1038)	(0.1023)	(0.1036)
Profitability	3.5615***	3.5615***	3.5838***	3.2974***	3.3108***
	(0.2334)	(0.2336)	(0.2334)	(0.2037)	(0.2053)
Constant	2.5979***	2.5975***	3.7133***	2.0872***	2.9219***
	(0.1996)	(0.1998)	(0.2376)	(0.1741)	(0.3203)
Year dummies	No	No	Yes	No	Yes
Industry dummies	No	No	No	Yes	Yes
Observations	6,973	6,973	6,973	6,973	6,973
R^2	0.6144	0.6144	0.6171	0.6897	0.6914
Adjusted R^2	0.6141	0.6140	0.6163	0.6890	0.6903

Notes: This table presents the results of the regression models used to for robustness test 1 with $\widehat{EUAVOL}$ and REUA. It contains their coefficients, with robust standard errors shown in parentheses, number of observations, R^2 and Adjusted R^2. All models employ a pooled OLS regression. Time and industry fixed effects are included in the 'Time FE' and 'Industry FE' models. The dependent variable is Tobin's Q. The main independent variable of interest is $\widehat{EUAVOL}$. Statistical significance levels at 10%, 5%, and 1% are denoted by *, **, and ***, respectively.

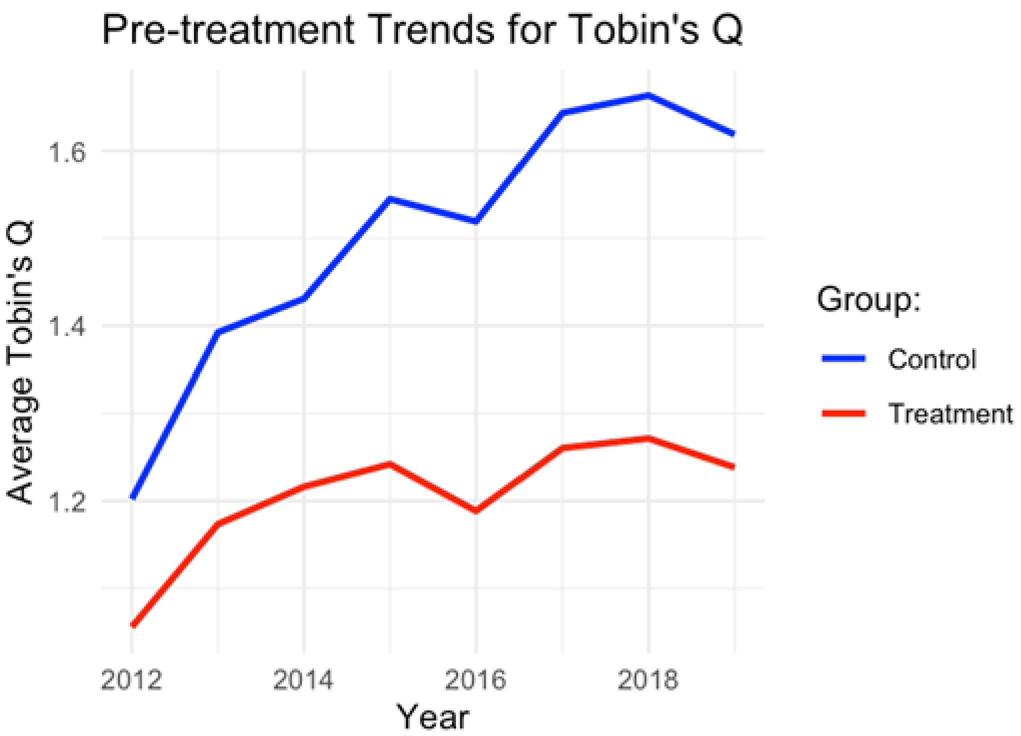
Table 21: Parallel Trends Test Results

	Dependent variable: Tobin's Q			
	Base Model	Time FE	Industry FE	Time + Industry FE
Time Trend	0.0420***	0.0472***	0.0387***	0.0443***
	(0.0064)	(0.0060)	(0.0063)	(0.0060)
Treatment	−0.0978	−0.0981	−0.3035***	−0.3038***
	(0.0671)	(0.0673)	(0.0625)	(0.0627)
Time Trend x Treatment	−0.0185*	−0.0184*	−0.0147	−0.0147
	(0.0108)	(0.0108)	(0.0106)	(0.0106)
Constant	−0.1881***	−0.2487***	0.4084***	0.3476***
	(0.0414)	(0.0400)	(0.0959)	(0.0956)
Year dummies	No	Yes	No	Yes
Industry dummies	No	No	Yes	Yes
Observations	5298	5298	5298	5298
R^2	0.0109	0.0124	0.3468	0.3484
Adjusted R^2	0.0103	0.0110	0.3452	0.3462
F Statistic	19.4449*** (df = 3; 5294)	8.3341*** (df = 8; 5289)	215.8270*** (df = 13; 5284)	156.8013*** (df = 18; 5279)

Notes: The table shows the parallel trends assumption test results for the DiD analysis used in hypothesis 4.

B Figures

Figure 4: Parallel Trends



Notes: The vertical axis represents the mean Tobin's Q for all the sample companies. The horizontal axis refers to the years of the sample's period.