Does the European Equity Market Show Evidence of a Carbon Premium?

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Dissertation written under the supervision of Carla Soares.

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Abstract

Risk measures have always been central to financial research. With global development towards sustainable solutions and decarbonization of the atmosphere, new risk classifications have emerged. Carbon risk, as a concept, is relatively new and related to the risks an entity faces by emitting greenhouse gases. Since the conception of the Paris Climate Agreement, all climate considerations have increased, and carbon risk has become a more prevalent risk factor.

This dissertation investigates whether the European Equity markets reflect a carbon premium from 2017 until the end of 2022. Through conducting a panel regression on the Eurostoxx 600, the analysis uncovers a statistically significant relationship between carbon emission and stock returns. The relationship is controlled for by including a wide range of known stock predictors and further analyzed by dissecting it into individual industries. We find evidence that the premium has risen relative to earlier periods in other markets, indicating that as awareness and regulatory focus on climate issues intensify, so does the associated risk premium.

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Resumo

As diferentes medidas de risco sempre estiveram no centro da investigação financeira. Com o desenvolvimento global em direção a soluções sustentáveis e à descarbonização da atmosfera, surgiram novas classificações de risco. O conceito de risco de carbono é relativamente novo e está relacionado com os riscos que uma entidade enfrenta devido à emissão de gases com efeito de estufa. Desde a conceção do Acordo Climático de Paris, todas as considerações climáticas aumentaram, e o risco de carbono tornou-se um fator de risco mais prevalecente.

Esta dissertação investiga se os mercados de ações europeus refletem um prémio de carbono desde 2017 até ao final de 2022. Através da realização de uma regressão de painel com as empresas do Eurostoxx 600, a análise revela uma relação significativa entre a emissão de carbono e os retornos das ações. A relação é controlada através da inclusão de um vasto leque de indicadores de previsão de ações conhecidos e é analisada posteriormente através da comparação entre sectores de atividade. Encontramos provas de que o prémio aumentou em relação a períodos anteriores noutros mercados, o que pode estar relacionado com o aumento da sensibilização ambiental e da regulamentação climática, o mesmo acontecendo com o prémio de risco associado.

Título: O mercado europeu de acções apresenta indícios de um prémio de carbono?

Autor: Ole Jacob Aamodt

Palavras-chave: Mercado Europeu de Acções; regressão em painel; prémio de risco de carbono; Europa

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Table of Contents

I. List of Tables

II. List of Figures

1. Introduction

Environmental developments and unfamiliar challenges for corporations and firms demand that investors expand their perspectives. Carbon risk is a primary example of this development and captures new considerations a rational investor should internalize. Carbon risk has several definitions, but all definitions incorporate the increased risk a firm faces due to carbon emissions. The definition, from ethical considerations to financial adjustments or regulatory influence, may vary greatly, but all coincide under the assumption that carbon emission negatively affects a business. Carbon risk is priced as the cost a firm faces by emitting greenhouse gasses. This cost has several ways of materializing: uncertainty of future cashflows, increased premiums on invested capital, or neglect of coverage from analysts. With the increased interest in the subject, research has surged, attempting to find evidence of a carbon premium and its potential price (Bolton & Kacperczyk, 2023).

2016 marked a pivotal shift in public awareness of climate-related issues. The 2016 Paris Agreement put climate issues at the forefront of global discussion and is continuously shaping public discourse. With the increased interest and attention drawn toward climate-related challenges, questions of whether investors and financial stakeholders have also incorporated a broader perspective in their investment decisions have risen. Assuming investors are rational and forward-looking, evidence in asset returns should provide insight into this question. Previous research has explored the relationship between carbon emissions and asset returns (Bolton & Kacperczyk, 2021, 2023; Zhang, 2022). However, these studies utilized data from the early 2000s to the mid-2010s and either focused on the American equity market or examined the relationship on a global scale. This presents an opportunity to examine the European equity market during a distinct timeframe, potentially reflecting shifts in investor preferences. Hence, the research question for the thesis is:

Does the European Equity market show evidence of a carbon premium?

To answer my research question, I will empirically assess the impact of carbon emissions on stock returns in the European equity market from the start of 2017 until the end of 2022. The analysis is conducted during a period marked by heightened climate awareness, which inherently enriches the study further. Moreover, utilizing fundamental financial and economic theories, such as risk-return relationships, asset pricing, and market efficiency, provides a robust framework for exploration. By integrating these concepts, the dissertation aims to contribute to existing literature by linking traditional theories and evolving market dynamics. Additionally, the dissertation will supplement an ongoing debate among academics where there are differences in results surrounding the effects of carbon emission and contradicting theories opposing the existence of a carbon premium (Bauer et al., 2022; Zhang, 2022).

The choice of Europe as the domain of the study is based on several dimensions. First and foremost, previous studies have yet to focus solely on the European Equity market, which provides the opportunity to go more in-depth and fill this knowledge gap. Secondly, the European capital market is one of the most developed financial markets in the world, potentially only surpassed by the United States. This ensures that the market being analyzed is liquid and well-developed, ensuring that the assumptions underlying fundamental financial theories are closer to being met. Thirdly, the Eurozone is showing great willingness to evolve and construct new legislation in an effort to tackle climate-related challenges. As brilliantly laid out by Broeders et al. (2024) *"the carbon premium in the European Market may be further developed than in other regions, reflecting the heightened progressiveness of the European Union's dedication to attaining net-zero status and the stringent implementation of comprehensive climate policies".* Assuming investors incorporate all available information, this is an element they should consider.

Europe's willingness to use legislative measures to tackle climate-related challenges is evident through several instances, but none more apparent than the enormous Carbon Credit market in the EU. The EU Emissions Trading System (ETS) is a carbon-based taxation that was first introduced in 2005 but went on a three-year trial phase before implementation began in January 2008 (Bolton et al., 2023). The system is a cap-and-trade system, where firms are obliged to hold enough Carbon Credits to cover their emission. Other sovereign nations and geographical regions have also created similar carbon-based taxation. However, the European Market is easily the most extensive and well-developed, representing around 87% of the total value of these trading schemes (Twidale, 2024).

The other central dimension of the following analysis is the time aspect of the study. As mentioned, prior literature has used data from an earlier time frame, leaving recent developments out of their scope. Increased awareness of climate-related challenges has risen significantly since the Paris Agreement's implementation, and financial markets have experienced a surge in green assets becoming progressively prevalent (Fahmy, 2022). Therefore, an exciting opportunity arises to examine whether this movement has affected investor's relationship towards carbon risk.

The thesis is structured into five chapters. Chapter 2 offers a comprehensive review of the existing literature, summarizing prior research and offering insights into anticipated outcomes based on the data utilized. In Chapter 3, the data for the analysis is introduced, along with an explanation of the methodology employed to address the research question. Chapter 4 provides a detailed examination of the results derived from statistical analysis, alongside a comparison with findings from relevant literature. Finally, Chapter 5 presents the conclusions drawn from the study, discusses the limitations encountered during the research, and offers suggestions for future investigations.

2. Literature Review

The concept of risk within the subjects of financial investment and pricing of securities is an old and well-examined topic. Literature has previously focused on determining and understanding the standardized risk factors. Factors such as currency risk, price risk, and market risk. However, as our world continues to develop, so do financial markets and our understanding of it, and recent studies have tried to examine new risk factors. Carbon risk, an unfamiliar concept, has gained traction during the 21st century in parallel with the progressive evolution of political policies (Broeders et al., 2024). The risk builds on multiple dimensions, further explained in Chapter 2.1, but creates the emergence of a premium on high-emitting firms. Both through financial elements as heightened risk and also from ethical considerations from socially responsible investors (Fatica et al., 2021). However, it is still a new and less studied subject than the traditional risk factors.

Studies related to Carbon risk and transmission risk for companies associated with high emission levels are still in their infancy, and evidence has varied and been described as patchy (Bolton & Kacperczyk, 2021). Hence, there needs to be more studies of how carbon risk is priced and whether or not it is associated with returns.

2.1 Theoretical Considerations

As studies related to Carbon Risk are relatively new, different definitions depend on what literature you rely on. Y. Wang et al. (2022) refers to carbon risk in corporate finance as "*the impact of society's transition to a low-carbon economy on firm value due to tightening regulation, changing consumer preferences, reputational damage, etc.*". Other definitions are instead centered around the negative impact unexpected price changes in carbon credits can have on corporations and portfolios (Carbon Risk, EDHEC Business School.). The following thesis will adopt a definition from Bolton & Kacperczyk (2021) that incorporates both dimensions. Their research describes carbon risk as all the related risks associated with greenhouse gas emissions and divides it into three dimensions. Primarily, since CO2 emissions are linked to energy consumption and the use of fossil fuels, investment returns are connected to the prices of fossil fuels and the associated commodity risks. Secondly, firms with higher emissions are also exposed to carbon credit pricing risk and potential regulatory interventions in an attempt to decarbonize the atmosphere. The latter plays a significant part in the study, as the EU is more active in decarbonization policies and implementing legislative measures (2050 Long-Term Strategy - European Commission). Lastly, carbon risk is also related to technological developments, innovation, and transition risk. The overarching goal of a carbon-neutral world creates an atmosphere where innovation and technological improvements in the energy sector are incentivized. Thus, companies heavily dependent on fossil fuels face greater technological risks from the emergence of lower-cost and green renewable energy sources.

In financial and economic theory, it is generally assumed that agents behave rationally. Therefore, based on this thesis's definition of carbon risk, forward-thinking investors should demand additional compensation for holding stocks with disproportionately high carbon emissions. The demand will be based on the expectation of challenges related to future cash flows from the risks associated with carbon emissions.

Firstly, if commodity prices on energy rise, high-consuming firms will face cash flow strain through increased costs. Business models are generally a "sticky" concept, and drastic changes to consumption usually demand intense investments. Therefore, both current and future cash flows are likely affected equally. Secondly, with a price increase in carbon credits, high-emitting firms will need to hold credits at a higher price, thus reducing their expected cash flow. With the continuous reduction of freely granted credits, future cash flows are expected to be influenced similarly. Lastly, regulatory changes and pressure towards a green transition create incentives for green investments, which can affect cash flows in the short- to medium-turn and hurt returns.

All these considerations relate to the theory of risk and return. A concept where an investor adjusts their risk appetite depending on their required rate of return. Given the potential sources of cash flow strains and risks emerging from carbon emissions, one can expect to find a positive connection between a company's greenhouse gas emissions and stock returns. This idea is known as the carbon risk premium hypothesis (Bolton & Kacperczyk, 2021). The theory suggests that holding stocks with a greater emission level also increases the general risk that investors face, and therefore, one should expect to find evidence of higher returns on average in high-emitting firms. Consequently, when subsequent papers explore the presence and extent of a carbon premium, they also examine the existence and magnitude of carbon risk.

2.2 Evidence of Environmental Considerations in Finance

American economists Eugene Fama and Paul Samuelson revolutionized finance in 1965 by presenting the *Efficient Market Hypothesis* (Fama, 1970). The theory suggests that market prices reflect all available information and that rational agents will instantaneously process and incorporate new information immediately. This includes all potential risks and opportunities related to an investment's value. Supported by Larry Fink's letter to CEOs from 2020, *"Climate risk is investment risk"*, rational agents should incorporate the potential carbon risk associated with an investment (*Larry Fink's Letter to CEOs*, BlackRock). However, climate change and its associated risks are new and unfamiliar subjects to investors, which can potentially lead to some mispricing. A study from 2018 showcased this mispricing and estimated that investors holding a portfolio of stocks going long companies with low carbon emission and short stocks with high emission generate positive abnormal returns (In et al., 2018). Results from the study sparked the idea of a *Carbon Alpha.* More recently, the theory met resistance from literature, as Bolton & Kacperczyk (2021) found evidence of the opposite in their study of the American equity market. Nevertheless, In et al. (2018) exemplify how carbon risk was not sufficiently incorporated into investors' asset pricing.

Atilgan et al. (2023) questioned whether the premium related to carbon risk is more due to mispricing than heightened risk. The study concluded that the carbon premium partially represents unexpected returns and thus mispricing. Firms with higher Scope 1, Scope 2, or Scope 3 emissions experienced superior earnings surprises and higher returns at the announcement of quarterly results. Further, it is determined that the returns associated with the quarterly report account for about 30-50% of the *Carbon Premium*. The study acknowledges how different research has used several methods for analyzing carbon risk and its estimated premium but does not try to solve the conflict (Bolton & Kacperczyk, 2021; Zhang, 2022). Its scope is instead centered on understanding the relationship between carbon emissions and earnings surprises.

Lastly, there are other instances of climate-related risks being shown to have an impact on asset prices. As previously explained, one of the related risks associated with carbon risk is the pricing of carbon credits. The European Carbon Credit tax system was implemented in 2008, and the taxation is related to an entity's emission. Prices of these carbon credits have increased drastically (*figure 1)*, and research has investigated whether they are a dimension of a stock's equity price. Bolton et al. (2023) concluded that *"firms with a significant shortfall in emission allowances, an increase in daily carbon prices was associated with a decrease in contemporaneous stock prices"*. Equally, the study also showed that for firms with a greater permit coverage, a price increase for the credits was associated with higher stock prices. Illustrating that investors are indeed capable of integrating all available information, including carbon risk related factors like carbon credit pricing.

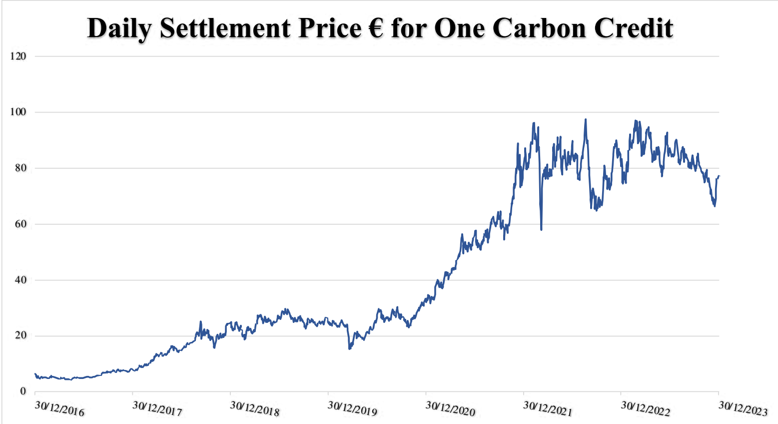

Figure 1. Price Development in European Carbon Credits 2017 – 2023
Source: Refinitiv Eikon DataStream

2.3 Estimation of the Carbon Premium across markets

The thesis draws inspiration from Patrick Bolton and Marcin Kacperczyk's work (Bolton & Kacperczyk, 2021, 2023). Their first work was related to an investigation of the American financial market, eventually leading them to expand their study to incorporate a worldwide scope (Bolton & Kacperczyk, 2023). Their global study is conducted on data from 2005 until 2018 and includes 14 400 firms across 77 nations. The study provides fascinating insight into a carbon premia's existence and its properties across geographical regions. Based on their findings, a carbon premium seems more challenging to identify in the Southern Hemisphere compared to Western developed countries. However, they contribute this difference to the more socially and economically diverse South and its lesser-developed financial markets. As this study is conducted on the European financial market, which is highly developed, we should expect robust evidence of a carbon premium. The study concluded that the carbon premium is statistically and economically significant, as a one standard deviation increase in Scope 1 emission is associated with a 1.1% increase in annualized stock return. It further concluded that the magnitude of the effect was more substantial when accounting for industries, reflecting the different adjustments investors incorporate across industries.

As part of the same study, no evidence suggested that stock returns are dependent on whether the energy consumed by a firm is from a renewable or fossil source. This suggests that investors do not prioritize the proportion of energy derived from fossil sources; instead, they focus on the aggregate amount of energy emission. Moreover, the study further indicated that countries with a more significant fraction of their energy production stemming from renewable energy sources resulted in a lower carbon premium. This observation aligns with the study on the American market, where investors are described as having a "schizophrenic" relationship towards carbon risk (Bolton & Kacperczyk, 2021). A relationship where investors sometimes incorporate nuances and complex structures and are less detail-oriented elsewhere. The study also investigated the year-by-year changes in the required carbon premium and examined the years around the Paris Agreement. When pooling all countries together, they found no significant premium before the agreement, but a significant and sizeable premium in the years after. This result is consistent with the perspective that the treaty has changed investors' awareness regarding climate change. As my timeframe will focus on the years after the agreement, we can expect to find evidence of a premium as investors have potentially become more considerate regarding climate change and associated risks.

Literature has also examined how carbon risk might manifest and the potential consequences. In line with the theory of efficient markets, the consequences should be incorporated and reflected through asset market prices.

A 2014 study examined the link between environmental externalities and the cost of capital. Using the implied cost of capital derived from analysts' earnings estimates, the study discovered that investors demand significantly higher expected returns on stocks excluded by environmental screens (Chava, 2014). Environmental screens disclose hazardous chemical emissions, greenhouse emissions, and environmental concerns from operations. The study also found evidence that lenders charge a higher interest rate on bank loans issued to firms with these environmental concerns.

More recently, De Nederlandsche Bank analyzed the European bond market to examine whether a Carbon Premium exists for high-emitting firms. Their findings indicate a significant premium, estimating that a doubling of Scope 1 and Scope 2 emissions results in an average increase of 6.6 basis points in the spread on a firm's corporate bonds (Broeders et al., 2024). The study also noted a substantial rise in the spread over the past years, from 6.6 in 2020 to 13.9 in 2022. Indicating that as climate awareness has risen, so has the estimated carbon risk premium.

Consequences of expensive financing are numerous, and as presented, expensive financing can occur through a required premium in the corporate bond market or through investors' required rate of return on invested capital. The main consequences take shape in the form of reduced investment in growth opportunities, cash flow strain through increased interest payments, and increased financial risk (Berk & DeMarzo, 2024). In line with Fama and Samuelson's theory, since the European financial market is highly developed, the market will incorporate these constraints immediately. If carbon risk is a fundamental concept, it will manifest through the carbon premium estimation and should be visible through an analysis of stock returns.

2.4 Evidence Against a Carbon Premium

Bolton and Kaczerpzyk's (2021, 2023) results are robust, but their research is not exempt from critique, and contrasting research has found evidence of a *Green Premium.* Zhang's investigation of carbon risk suggests that Bolton's and Kacperzyk's findings result from their econometric setup and are, hence, invalid (Zhang, 2022). Zhang criticizes the use of the linearity assumption in OLS regression and argues it is laying grounds for a look-ahead bias. The study documents a Green Premium in the American equity market nonparametrically through Zhang's setup, considering the release lags in the carbon data. This consideration includes close monitoring of the disclosure of data from each vendor and aligning the releases in the estimation model. The evidence is in line with Pastor et al. (2022) where they relate a Green Premium to the *ESG score* of a company, using the MSCI environmental score as a proxy. The MSCI environmental score incorporates 13 different characteristics, with emissions being one of the thirteen, as well as raw material sourcing, toxic waste, green building, and renewable energy. Zhang (2022) acknowledges possible pitfalls in the research and that the observed *Green Premium* in the US might be attributed to data mining, given the lack of similar evidence on a global scale. They further suggest that it could be due to shifts in investor preferences that have differed widely across nations, generating cross-country variation.

Lastly, there has been research relating the carbon premium to investors' moral preference rather than their risk appetite. Inspired by Hong & Kacperczyk (2009) researchers have questioned whether investors will shun away from high-carbon stocks due to the harm these companies cause to the environment. The study from 2009 investigated how investors shun away from *sin* stocks, publicly traded companies that are involved in producing alcohol, tobacco, and gaming. Evidence showed that norm-constrained institutions with specific mandates, such as pension funds, stayed away from these stocks and that these types of companies experienced less coverage by analysts overall. Pedersen et al. (2019) found evidence that investors will optimally construct a portfolio along the ESG-efficient frontier. The paper further argues that as more investors shun companies in *brown* industries, high-emitting firms will experience a decrease in share price because a subset of investors will morally disinvest in them. This is further supported by Bolton & Kacperczyk (2021), who found evidence that institutional investors hold a significantly smaller portion of high Scope 1 emission firms. The study further disaggregates institutional investors into categories and finds that insurance companies, pension funds, and mutual funds are underweighted in these companies. Meanwhile, hedge funds, which are more natural arbitrators, do not display the same pattern.

In conclusion, there is conflicting evidence regarding the manifestation of carbon risk in equity prices and the interpretation of the required carbon premium for holding high-emitting stocks. However, substantial evidence supports the existence of this premium, both globally in international equity markets and within the European bond market. Literature also suggests increased carbon risk and its estimated premium in recent years, coinciding with heightened climate awareness. The dissertation will add value to the literature by analyzing a recent period in a well-developed and significant financial market, providing further insight into a new and challenging subject.

Considering the literature, data selection, and timeframe, I anticipate that my analysis will indicate significant evidence of a positive relationship between greenhouse gas emissions and stock returns.

3. Data and Methodology

3.1 Selection of Data

In order to capture a broad and diverse selection of companies to represent the European financial market, the following analysis is conducted on the European equivalent of the S&P 500, the Euro Stoxx 600. The Index is capped at 600 firms, weighted based on market capitalization, and covers Europe's diversity and all its industries. As of spring 2024, the most prominent members of the Euro Stoxx 600 are Novo Nordisk, ASML Holding, Nestle, and LVMH Moet Hennessy (*1-STOXX® Europe 600*, EuroNext). Due to requirements of data on yearly greenhouse gas emissions, not all 600 current members of the Index are included in the analysis, but rather those companies that have reported their emissions from 2017 and onwards. After stripping away the non-reporting entities, the remaining number is *471* individual companies, with data spanning from 2017 until the end of 2022. As we progress towards the EU's goal of a greener and more sustainable future, all companies will eventually have to report their yearly emission. In line with the EU's Corporate Sustainability Reporting Directive, all firms complying with two criteria must report yearly emissions from 2024 onwards (*Corporate Sustainability Reporting - European Commission*).

Two methods can solve issues with non-reporting entities. As explained, this analysis will remove the non-reporting companies from the sample and only include the firms that disclose their emission. A second way of solving the issue is by using estimated emissions provided by various third-party data sources. Bolton and Kacperczyk utilize the estimation method in both studies on carbon risk (Bolton & Kacperczyk, 2021, 2023). However, this method will not be utilized, as shown by Aswani et al. (2024) using either reported or estimated values for emission can have profound effects on the empirical results. Hence, only including reported numbers from the companies themselves heightens the validity of the analysis.

The *471* firms included in the analysis are from 17 different European Countries. The companies are mainly located in what we would define as Western Europe, with the most prominent contributors being *the United Kingdom, Germany, and France***.** Due to currency variations between reported entities, a standardization using the euro has been applied, making the observations and analysis easier comparable. As the firms are all European and almost all members of the Union, the entities are subject to the EU's jurisdiction. This results in limited legislative heterogeneity between the firms.

Country	**Firm Year Observations**	**Average Emission**
United Kingdom	122	2 073 093
France	67	2 962 537
Germany	53	6 103 913
Switzerland	41	4 015 792
Sweden	34	483 537
Italy	27	5 631 241
Netherlands	23	641 188
Spain	22	3 682 878
Finland	18	2 048 467
Denmark	17	2 501 784
Norway	12	170 561 103 420
Ireland	9	5 484 669
Austria	7	4 368 432
Belgium	6	1 042 865
Luxembourg	5	34 008 670
Portugal	4	4 940 568
Poland	3	7 606 047

Table 1. Country Statistics of Emission
Average Emission is reported in Metric Tonnes for all firms included in the sample period 2017-2022.

Providing further insight into the analysis, the firms are sorted into their respective industry. Carbon emissions naturally depend on the industry, as some activities emit more carbon (for example, the direct emissions of a transport company are higher than those of a financial firm).

Therefore, some industries may be subject to stricter legislation and more scrutiny from stakeholders, which might affect the firms' relation to carbon emissions and realized returns. The analysis utilizes the ICB's classification of each entity. The Industry Benchmark Classification is structured into 11 unique industries and has been adopted by exchanges such as the NASDAQ, London Stock Exchange, and Euronext (*Industry Classification Benchmark (ICB)*).

Industry	**Firm Year Observations**	**Average Emission**
Technology	17	160 015
Telecom	18	694 942
Health Care	39	379 300
Financials	86	51 715
Real Estate	25	41 955
Consumer Discretionary	63	1 581 953
Consumer Staples	38	1 000 731
Industrials	107	3 495 151
Basic Materials	35	10 988 768
Energy	18	115 345 420 507
Utilities	25	15 914 395

Table 2. Industry Statistics of Emission
Average Emission is reported in Metric Tonnes for all firms included in the sample period 2017-2022.

Lastly, as a measure to further inspect the sample data, the yearly percentage return for each stock and the natural logarithm of total emission is illustrated in a scatterplot (*figure 2)*. A simple visual analysis of the plot does not indicate any relationship between carbon emission and stock returns, which shows a correlation of -0,06. Hence, data elements suggest a more substantial analysis is recommended to extract information. When considering the panel structure of the data and the possibility that each entity has some variation within, certain analytical methods that take into account the structure of the data become more relevant. The method of choice is further discussed in *Chapter 3.2.*

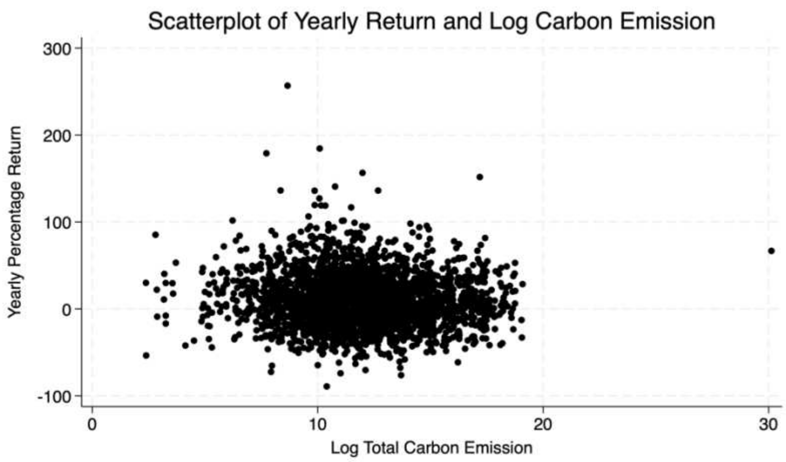

Figure 2. Scatterplot of Yearly Percentage Return and Log Total Carbon Emission for all firms included in the sample period 2017-2022.

3.2 Methodology

To answer the research question, the following analysis will make use of panel regression techniques as its methodological design. A panel regression is the most fitting design because our observations are related to individual firms and span from 2017 until 2022. The panel considers two dimensions, time and entity, and the research design follows the same structure as Bolton & Kacperczyk (2021). The panel is unbalanced, as some firms have missing observations for a certain number of years, but firmly balanced in the sense that it is not to the detriment of the analysis. The regression equations used to analyze the subject are structured in the following order:

$$Yearly\ Return_{i,t} = a_0 + a_1 Focus\ Variable_{i,t-1} + a_2 Controls_{i,t-1} + \mu_i + \varepsilon_{i,t}$$

Regression Equation Structure

Our primary coefficient of focus is a_1, as it relates to the impact emission has on our firms' yearly return. The focus variable is interchangeable, depending on which hypothesis is being tested, but will always be some proxy for Carbon Risk. The first analysis will be conducted on the natural log of total emissions and divided into each Scope separately. The second analysis will be conducted on the percentage change from year to year in emission, and each scope will be controlled independently. The third analysis will control for the non-linear relationship between the estimated carbon premium and total emission. This will be conducted by regressing yearly returns on Log Emission but also employing a first-difference estimator. The last element to be considered is carbon intensity. Carbon intensity is calculated as total emissions divided by total sales. *Figure 2* contains all control variables in the panel data regression, while Chapter 3.5 thoroughly explains each element.

Control Variables
Return on Equity
Log Market Value
Book-to-Market
Leverage
Investment Rate
Log Property, Plant, Equipment
Sales Growth

Figure 3. All Control Variables

By analyzing the different emission measures, we attempt to increase the robustness of the research and use variables capturing all aspects of carbon risk explained in *Chapter 2.1*. Therefore, I investigate whether investors' relationship towards emissions depends on total output, yearly change, and intensity while also controlling for a non-linear relationship in the estimated premium. The dependent variable is the return for firm *i* for any given year *t*. The control variables follow the same structure in terms of time and entity. They are selected due to their property as known predictors of stock returns, increasing the robustness of our analysis. The model also utilizes robust standard errors as the second element of increasing the robustness and validity of the estimated results. The full Stata script for estimations can be seen in *Appendix 1*.

The last element of our model is an entity fixed effect, μ_i. The entity fixed effect is included due to the assumption that each entity has unobserved characteristics that correlate with my independent variables. By including this fixed effect, we can account for unobserved factors, allowing for better isolation from the impact of our variable of interest (Wooldridge, 2020). Further explanation of each variable in the equations is provided in chapters 3.3, 3.4, and 3.5, while full summary statistics of all variables can be examined in Table 3.

Variable	Observations	Mean	Std. dev.	Metric
Yearly Return of Equities	2827	10,17	30,86	Percent
Log Carbon Emission	2794	11,88	2,73	Natural Log
Log Scope 1 Emission	2620	10,65	3,16	Natural Log
Log Scope 2 Emission	2554	10,77	2,45	Natural Log
Percentage Change of Emission	2753	4,12	79,39	Percent
Percentage Change Scope 1	2648	15,49	227,01	Percent
Percentage Change Scope 2	2653	53,68	2064,88	Percent
Carbon Intensity	2795	0,16	0,42	Ratio
Carbon Intensity Scope 1	2620	0,24	1,27	Ratio
Carbon Intensity Scope 2	2619	0,06	0,32	Ratio
Return on Equity (Winsor 1%)	2809	15,07	16,28	Percent
Log Market Value (Winsor 1%)	2822	9,22	1,08	Natural Log
Book-to-Market (Winsor 1%)	2775	0,64	0,55	Ratio
Leverage	2824	0,26	0,36	Ratio
Investment Rate (Winsor 2,5%)	2820	0,03	0,03	Ratio
Log Property, Plant, Equipment	2817	14,33	1,95	Natural Log
Sales Growth (Winsor 1%)	2825	7,35	20,62	Percent
Sales	2825	16 700 000	29 300 000	Euros
Total Emission	2796	3 083 800	10 400 000	Tonnes
Direct Emission Scope 1	2620	2 490 527	8 975 832	Tonnes
Indrect Emission Scope 2	2554	423 069	1 333 775	Tonnes
Market Value	2822	19 195	29 598	Mill. Euros
Property, Plant, Equipment	2822	7 044 463	14 300 000	Euros

Table 3. Descriptive Statistics of all variables

The final feature of the statistical analysis involves examining each industry individually and isolating the analysis to only EU member countries. As outlined in *Chapter 3.1*, all companies have been categorized according to the ICB classification system, and we can gain deeper insights into how carbon risk materializes by grouping them into peer clusters. The same chapter also presents country-level data, and I will also investigate whether membership in the EU creates significant differences in the estimated carbon premium.

3.3 Variable of Focus

As explained, our variables of focus will always be related to carbon risk and capture elements of the definition used in this dissertation. The first variable is Log Emission. The beta for log emissions shows how a percentage change in emissions affects returns. It measures the sensitivity of returns to these changes. The second variable under consideration is percentage change. The estimated coefficient for percentage change will indicate how variation in the growth rate of emission influences stock returns. The third variable under focus is the first-difference estimator for carbon emission. The first-difference estimator allows us to analyze a potential non-linear relationship in the estimated carbon premium. The last variable, Carbon Intensity, is an efficiency indicator. A lower ratio suggests that a company is producing more revenue for every unit of carbon emitted, representing higher environmental efficiency and possibly more sustainable operations.

Firm-level carbon data are retrieved from Refinitiv Eikon using DataStream, and as mentioned previously, only reporting entities are included in the sample, and estimation for non-reporting firms is not applied. The data is reported in metric tonnes of emission and includes the following gasses: *Carbon Dioxide (CO2), methane (CH4), nitrous oxide (N20), hydrofluorocarbons (HFCS), perfluorinated compound (PFCS), sulfur hexafluoride (SF6) and nitrogen trifluoride (NF3).* For simplicity, I continue mentioning carbon emissions as covering the emissions for all of these greenhouse gasses.

In this thesis, emission is a consequence of direct emission (Scope 1) and indirect emission (Scope 2) and follows the Greenhouse gas (GHG) protocol. The GHG Protocol is a joint initiative of the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). It came to life in 2016 as an attempt to create an international standard for corporate accounting and reporting emissions, categorizing greenhouse emissions into three scopes (*Greenhouse Gas Protocol | World Resources Institute*, 2023).

Scope 1 of the GHG Protocol includes direct greenhouse gas emissions from sources controlled or owned by an organization. This includes emissions from sources such as fuel combustion, physical or chemical processing, and fugitive emissions (*What Are Scope 1, 2 and 3 Emissions? | Deloitte*). It is the easiest to measure, and a subset of the observed entities have been tracking this before the implementation of the GHG Protocol. Scope 2 of the protocol standardizes how corporations measure emissions from indirect sources, such as purchased or acquired electricity, heat, and cooling (*Scope 2 Guidance | GHG Protocol*).

The GHG protocol also refers to a third emission measure, the third Scope. The third scope standardizes how an entity measures emissions from its entire *Corporate Value Chain*. This includes the process from the initial purchase of raw materials to the disposal of the products itself (*Corporate Value Chain (Scope 3) Standard | GHG Protocol*). The third scope is recognized as the most complex dimension to measure accurately. Thus, data is scarce. Hence, in this dissertation, Scopes 1 and 2 are merged to measure total emission and normalized using the natural log scale. Year-over-year is measured by calculating the change in emission from year t to $t+1$. Lastly, carbon intensity is measured as total emissions divided by total sales. All measures will also utilize a lagged time dimension, as information on emissions in year t is only made publicly available in year $t+1$.

Concerning our research question and hypotheses. I expect the coefficients to be positive and significant. Indicating a positive relationship between stock returns and emissions due to the related carbon risk, in line with the hypothesis of an existing carbon premium in the European equity market.

3.4 Dependent Variable

The empirical analysis of stock returns uses yearly returns as the dependent variable. The data is extracted from Refinitiv Eikon, using their Return Index to create a proxy for yearly returns for each firm. The use of the Return Index over prices is because prices would not capture the potential dividend payments distributed during the year. Therefore, the Return Index is a superior measure for calculating yearly returns, reflecting the actual realized return for holding stock i in year t. The dataset contains all observations without any trimming or winsorizing applied. This contrasts with Bolton and Kacperczyk (2021), who utilized monthly data and encountered numerous instances of returns exceeding 10,000% within a month, leading to noticeable mispricing in the firms. Such extreme outliers are less likely to occur over a year, and our statistical analysis does not indicate their prevalence. The variable is reported in percentage terms, and for descriptive statistics, refer to *Table 3*.

3.5 Control Variables

As mentioned earlier, some of the control variables included in the regressions are selected based on their ability to predict stock returns and thus replicating the research design of Bolton & Kaczpercyk (2021, 2023). Others have been specifically chosen to neutralize the effect CO2 emission has on stock returns. Critics might oppose the idea that if higher returns are associated with higher emissions, it is simply a reflection of increased production. Thus, variables like Sales growth, the natural logarithm of property, plant, and equipment (Log PPE), and investment rate (IR) are incorporated to address this potential pitfall.

The variables are lagged compared to our dependent variable, following the same approach as the variable of focus, in order to reduce endogeneity issues. Bolton & Kacperczyk (2021, 2023) used all of the same control variables in their studies but even incorporated more measures as their frequency of observations differs from ours. A descriptive presentation of each variable and how the estimates have been calculated follows.

- $ROE_{i,t-1}$. It is a proxy for a firm's earnings performance, better known as Return on Equity. Return on Equity is calculated as net income over an average of the last year's and current year's common equity multiplied by 100 (*Variable reported in percent*).
- $LogSize_{i,t-1}$. It is the natural logarithm of the market value measured at the end of each year.
- $BM_{i,t-1}$ is a measure of a firm's book-to-market value and is calculated as the book value of ordinary common equity divided by the market value of equity at the end of each year.
- $Leverage_{i,t-1}$ is a measure of each entity's leverage based on its capital structure. The variable is calculated as Net debt over Total Capital at the end of each year.
- $IR_{i,t-1}$ represents the firm's investment rate and is measured as Capital Expenditures (CAPEX) over the book value of assets.
- $LogPPE_{i,t-1}$ is a measurement representing the amount of property, plant, and equipment each entity has on its balance sheet. It is further normalized using the natural logarithm.
- $SalesGR_{i,t-1}$ is a measurement of an entity's sales growth year over year and is calculated as $\left(\frac{Sales_t - Sales_{t-1}}{Sales_{t-1}}\right) * 100$ (*Variable reported in percent*).

A common characteristic for all control variables is that they are utilized as either a ratio or natural logarithm. This enhances the robustness of the analysis as none of the variables are used in unadulterated values but rather normalized. Some variables are winsorized to account for extreme outliers and potential misreporting in the data, following the example set by prior research (Bolton & Kacperczyk, 2021; Zhang, 2022). Book to market, Leverage, ROE, and Sales growth are winsorized at 1%, while Investment rate is winsorized at 2,5%. By winsorizing the variables, we do not trim away any observations but instead change the observed tail observations with values from the 1^{st} and 99^{th} percentile (2.5^{th} and 97.5^{th} for IR).

The controls are anticipated to show statistical significance in the regression analyses, although the direction of their effects is not explicitly predicted. This stems from one of the main characteristics of financial markets; if a particular financial ratio could accurately forecast returns, the market would quickly integrate this information, eliminating any arbitrage opportunities (Xue & Zhang, 2008). Nonetheless, research and literature have demonstrated a stronger connection between stock returns and some of the specified controls.

Book-to-market and size are recognized ratios used to explain average stock returns. Fama & French (1992) established a solid relationship between average returns and book-to-market, even after controlling for other factors. A high book-to-market value indicates that the market values the company's equity cheaply compared to its book value. In other words, a high book-to-market can indicate underpricing, while a low book-to-market could indicate overpricing and well-developed and efficient markets should eliminate any mispricing immediately.

3.6 Hypotheses

Considering the data selection described in the sections above, the timeframe of focus, and the literature presented in *Chapter 2*, we can formulate a set of specific expectations for the analysis. All hypotheses are related to carbon emission and its impact on stock returns.

H1: Log total emission will indicate a statistically significant relationship with stock returns and indicate the existence of a European carbon premium. The relationship between my estimated coefficient and the dependent variable is expected to be positive but also deemed at a level where we can confidently state that it has an economic impact. As for all financial and economic research, an essential aspect of determining the significance of an estimator is to consider whether the value is of a size where it is deemed impactful economically.

H2: Yearly changes in carbon emissions will be statistically significant and have a positive relationship with stock returns. Similarly, as with total emissions, expectations are that the variable will have an economically significant impact on stock returns and indicate that variation in the growth rate of emission influences stock returns.

H3: Log Emissions and the first-difference estimator will be deemed statistically significant and indicate a non-linear relationship in the estimated carbon premium. A positive and significant first-difference estimator would imply that as emissions increase, so does the marginal premium and vice versa.

H4: Carbon intensity will be proven to have a statistically significant impact on stock returns. The relationship will be based on the associated carbon risk due to transition risk for less efficient firms. As outlined earlier, intensity can be interpreted as a measure of environmental efficiency, and as presented in Chapter 2.1, one dimension of carbon risk referred to in this thesis is transition risk. Therefore, being efficient with the resources you consume might mitigate a firm's risk exposure, while non-efficient firms with high carbon intensity face greater risk.

4. Results

The results are divided into four main sections, each focusing on thoroughly answering each hypothesis. The first section presents evidence from stock returns regressed on total emissions. The second section will discuss the effect of yearly emission changes. The third section presents the result from estimating non-linear effects in the carbon premium. Finally, the last part presents the results from the intensity analysis. The last element outside of the primary analysis is a regression of only EU member countries. This is done to control potential differences between the whole European equity market, and only the membership countries.

A general presentation of the statistical output from the model will be presented in section one, explaining the measures provided by the regression. However, moving onward from the first analysis, each section will narrow its scope and focus on the individual differences between each regression. Emphasizing an economic interpretation to provide easily digestible insight into the European carbon premium. Additionally, the first section will briefly touch on the control variables, though these will not be discussed in detail since they are not crucial to the research question.

4.1 Total Emission – Section One

Table 4 presents the statistical output from the regression related to hypothesis 1. Stock returns are either regressed on Log Carbon Emission, Log Scope 1 Emission, or Log Scope 2 Emission, plus the selected control variables. The within variation from the regressions is around 0,33, implying that our model explains 33% of the change within an entity year-over-year. This metric is crucial given the usage of fixed effects in the modeling approach. The problem with standard R2 for fixed effect models is that the value will primarily be driven by the fixed effects rather than by the regressor of interest. The within-R2 solves this issue because it computes the R2 after every variable has already been demeaned with respect to the fixed effect (Correia, reghdfe FAQ). The F-stat is highly significant for each regression (Prob > F = 0,000), reinforcing the model's robustness and suitability for the data.

Table for Hypothesis 1 - Total Emission

Variables	**(1)**	**(2)**	**(3)**
Log Carbon Emission	2,520**		
	(1,178)		

Log Scope 1 Emission		1,341	
		(1,390)	
Log Scope 2 Emission			0,046
			(1,131)
Return on Equity	0,395***	0,417***	0,417***
	(0,074)	(0,082)	(0,081)
Log Market Value	-51,619***	-53,769***	-53,640***
	(2,711)	(2,978)	(3,007)
Book-to-Market	10,973***	10,045**	10,028**
	(3,898)	(4,096)	(4,090)
Leverage	-9,454**	-12,391**	-10,712**
	(4,265)	(4,807)	(4,685)
Investment Rate	-36,632	-21,865	-28,312
	(56,577)	(60,347)	(61,324)
Log Property, Plant, Equipment	10,555***	10,862***	10,902***
	(1,741)	(1,866)	(1,868)
Sales Growth	0,069**	0,058*	0,058*
	(0,031)	(0,033)	(0,033)
Constant	294,966***	326,582***	338,309***
	(29,963)	(32,076)	(32,765)
Prob > F	0,000	0,000	0,000
Within R-Squared	0,325	0,337	0,337
Observations	2 715	2 473	2 475

Table 4. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

The LogTOT coefficient is statistically significant at the 5% level, with a T-statistic exceeding an absolute value of 1,96. This finding aligns with research by Bolton & Kaczerpzyk (2021, 2023) and suggests a linkage between stock returns and carbon emissions. The interpretation is that investors holding stocks with greater greenhouse gas emissions, thereby consuming higher carbon risk, will require a premium on their invested capital, and expect higher returns. This notion utilizes historical returns as an indicator of expected returns and is not without its critique. Botosan et al. (2010) criticized the use of realized returns as a stand-in for expected returns, labeling them as noisy proxies and unreliable estimates. Nonetheless, this approach has been applied by both Bolton & Kaczerpzyk (2023) and Zhang (2022), providing support to the hypothesis under consideration.

In order to better understand the economic effect the model presents, *Appendix 2* outlines the mathematical deduction of a 10% increase in total emissions. The result indicates that a 10% increase in emissions should yield a yearly increase in returns of 0,225 percentage points. Similarly, *Appendix 3* outlines the effect of one standard deviation emission increase on stock returns. A one standard deviation increase in emission would lead to an increase of 6,88 percentage points. Comparing these results with Bolton & Kacperczyk (2021) which analyzed the American equity market, we witness higher estimates for the carbon premium. Their estimates suggested that a one standard deviation increase in Scope 1 emission increases returns by 1,8 percentage points, and a one standard deviation increase in Scope 2 emission led to a 2,9-percentage point increase. Totaling an estimated growth of 4,7 percentage points.

Looking individually at the scope 1 and 2, the building blocks for our total emission variable, neither scope is deemed significant at any level. The result is surprising since they are the foundation for the significant estimator. An interpretation of the results suggests that our data does not indicate that investors care about each scope individually but rather the aggregated amount of total emission. The results differ from Bolton & Kacperczyk (2023) where each scope was individually deemed significant. The differences could result from different frequencies in the data points and because our data sample is not vast enough to establish any relationship between the variables.

The heightened premium estimated from the analysis is to be expected, given the differences in timeframe and different markets analyzed. Referring to previous discussions, the heightened climate awareness since the signing of the Paris Agreement was expected to increase the estimated effect of carbon risk, and the results align with the hypothesis. However, geographical differences make the comparison not directly applicable but serve as a sufficient indicator of changes due to the noteworthy similarities between the American and European financial markets.

4.1.1 Industry Analysis

Carbon emissions can differ substantially across industries, and one could expect that the carbon premium is priced differently according to the industry. I, therefore, rerun the same regression by looking at each industry separately, i.e. interacting the log of carbon emission with the industry identifier, which means cross-referencing each unique industry to its carbon emission. Given the data selection and number of observations, conducting the analysis may be too demanding. Nonetheless, it can provide fascinating insight into the European carbon premium. Table 5 is a comprehensive summary of the statistical output from the estimated regression. Focusing on the specific industries deemed significant for Total Emission, Telecom, and Energy indicates a positive and statistically significant relationship between stock returns and total emission.

Table for Hypothesis 1 - Total Emission # Industry Dummy

Variables	**Total Emission**	**Scope 1**	**Scope 2**
Technology	3,666	-6,572	-2,013

	(9,875)	(6,215)	(6,484)
Telecom	15,161***	33,474***	2,334
	(5,471)	(9,563)	(8,030)
Health Care	10,031	9,259*	2,904
	(7,304)	(5,634)	(3,937)
Financials	4,651	2,611	2,024
	(3,326)	(2,308)	(2,060)
Real Estate	-2,612	-0,976	-2,361
	(3,645)	(3,599)	(3,140)
Consumer Discretionary	-0,314	-8,074	-0,130
	(5,155)	(4,717)	(3,831)
Consumer Staples	6,052	3,141	-1,433
	(8,238)	(4,391)	(4,317)
Industrials	3,640	6,375**	1,738
	(3,796)	(2,956)	(2,246)
Basic Materials	2,255	-5,061**	-7,007***
	(8,828)	(2,194)	(1,736)
Energy	1,761***	0,023	-2,893
	(0,654)	(6,232)	(6,982)
Utilities	-0,113	4,343	3,490
	(4,494)	(4,195)	(3,241)
Return on Equity	0,396***	0,436***	0,417***
	(0,074)	(0,083)	(0,081)
Log Market Value	-51,866***	54,467***	54,116***
	(2,688)	(2,994)	(3,004)
Book-to-Market	10,860***	10,049**	9,860**
	(3,921)	(4,111)	(4,121)
Leverage	-9,825**	-11,270**	-10,317**
	(4,326)	(4,814)	(4,676)
Investment Rate	-34,758	-32,134	-31,591
	(58,339)	(60,950)	(62,005)
Log Property, Plant, Equipment	10,497***	10,842***	10,807***
	(1,761)	(1,868)	(1,895)
Sales Growth	0,071**	0,060*	0,059*
	(0,031)	(0,033)	(0,033)
Constant	284,153***	317,096***	341,668***
	(34,219)	(32,062)	(33,471)
Prob > F	0,000	0,000	0,000
Within R-Squared	0,325	0,346	0,340
Observations	2 679	2 473	2 475

Table 5. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

Telecom and Energy being statistically significant is surprising, given the different characteristics of the industries and the drastic variance in average emissions from companies included in the analysis. Energy is the highest average emitter, and Telecom is in the bottom five (*Table 2*). However, the fact that Energy is shown to impact the carbon premium supports the hypothesis under consideration. Energy is by far the highest emitting sector in the data sample and aligns with the theory that high-emitting firms are exposed to an increased risk, and investors would require a premium on their invested capital. On the other hand, industries with higher averages, such as Basic Materials, Industry, and Utilities, are not proven statistically significant for total emission, even though they are in the top four for average emission.

However, when dissecting each scope of emission individually, some other sectors with high average emissions are deemed statistically significant. Industrials are deemed significant for Scope 1 emission with a positive coefficient. For Basic Material, both Scope 1 and Scope 2 emissions are deemed significant, but the sign for the coefficient has changed to negative. This contradicts the hypothesis and suggests that an increase in these scopes would decrease realized returns. While the results are surprising, general financial theory might solve this issue. The goods and services delivered by this specific industry require firms to be extremely cost-efficient, and an increase in resources used can be to the detriment of the profits generated. This could influence current cash flows and future expectations, reducing the value of equity.

Reviewing the total output jointly, there are indicators that the estimated carbon premium in the European equity market depends on which industry a firm operates within and the average level of emission stemming from that industry. Sectors such as Energy and Industrials are at the top of the highest average emissions, and the results suggest that high-emitting industries are more exposed to a carbon premium. One notion that must be considered when looking at the results is related to the third Scope of emission, the *Corporate Value Chain.* One can argue that certain industries in the sample have a substantial amount of their emissions stemming from this scope and that more industries would show a statistically significant relationship if this dimension were included. Nevertheless, when looking at the direct and indirect emissions, the industry that is clearly the highest consumer of resources (Energy) is proven to be statistically significant.

4.2 Yearly Change – Section Two

The second section dissects stock returns regressed on the yearly percentage change in carbon emission. Prior research estimated that a one standard deviation increase in the yearly percentage change for emission, resulted in a corresponding increase of 2,17% in stock returns (Bolton & Kacperczyk, 2023). However, that study was conducted on the global market and did not concentrate on one specific region. Table 6 presents the complete statistical output from the panel data regression.

Table for Hypothesis 2 - Percentage Change			
Variables	**(1)**	**(2)**	**(3)**
Percentage Change Total Emission	-0,001		
	(0,010)		
Percentage Change Scope 1		0,001	
		(0,002)	
Percentage Change Scope 2			0,001
			(0,000)
Return on Equity	0,392***	0,385***	0,389***
	(0,074)	(0,078)	(0,077)
Log Market Value	-52,696***	-51,682***	-52,491***
	(2,792)	(2,815)	(2,716)
Book-to-Market	10,582***	11,741***	11,135***
	(4,023)	(4,229)	(4,213)
Leverage	-10,002**	-9,949**	-9,624**
	(4,340)	(4,436)	(4,438)
Investment Rate	-29,971	-37,460	-39,499
	(57,216)	(59,688)	(59,454)
Log Property, Plant, Equipment	10,638***	10,118***	10,469***
	(1,789)	(1,904)	(1,936)
Sales Growth	0,068**	0,067**	0,068**
	(0,032)	(0,032)	(0,032)
Constant	334,080***	331,768***	334,564***
	(26,998)	(27,915)	(27,985)
Prob > F	0,000	0,000	0,000
Within R-Squared	0,324	0,323	0,326
Observations	2 679	2 576	2 581

Table 6. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

The estimated coefficient for yearly changes is not statistically significant at any level. Based on the previous regression (Total Carbon Emission), a natural assumption is that carbon emission changes would also indicate a positive relationship with stock returns. As presented, the comparison with Bolton & Kaczperczyk (2023) is not without its differences. Different geographical regions, as well as their model were regressed on monthly returns instead of yearly.

The same study divided its global analysis into four geographical regions. They separated it into North America, Europe, Asia, and what they labeled as The Southern Hemisphere. Their data is based on a different sample and conducted in a different timeframe. However, when dissecting the statistical output from the European analysis exclusively, there are indicators of similar evidence. Neither emission changes in Scope 1, 2, nor 3 are deemed statistically significant for the European region. This differs from the North American and Asian markets, where almost all of the scopes were found to be statistically significant to some extent.

Attempting to understand how this output occurs is a difficult task. The result might be due to data mining and coincidences. However, another plausible explanation is that the differences result from legislative variances and how each political region attacks decarbonization.

Generally, the findings from my analysis on percentage change differ from prior literature. Neither Total change nor the individual scopes alone show any statistical relationship. Given that my results on Log Emissions were quite similar to prior research, the results were surprising but could be due to differences in the data sample. My data are limited compared to those studies, the timeframe under consideration is different, and the data points are of a lower frequency.

4.2.1 Industry Analysis

Following the same structure as previously, I rerun the same regression by looking at each industry separately, i.e. interacting the percentage change of emission with the industry identifier. The results are presented in *Table 7*, with each column presenting the results for total change, scope 1 change, and scope 2 changes.

Similarly, as with the generalized analysis for Percentage change, there does not seem to be any relationship between the emission growth rate and stock returns, even when controlling for individual industries. There are some instances of statistical significance (Utilities Scope 1, Industrials Scope 1, Real Estate Scope 1, and Consumer Discretionary Total), but the overall output is relatively weak. Industrials are again shown to be significant for Scope 1, direct emission, suggesting that emissions from owned and controlled operations are an essential measure for this sector.

None of the industries are considered significant for Scope 2 emissions. However, as explained in the previous section, my general findings on percentage change and equity returns differ from prior literature. This is likely due to the frequency of data points and the limited size of the data sample rather than the absence of a relationship between stock returns and percentage change.

Table for Hypothesis 2 - Percentage Change # Industry Dummy

Variables	**Total Emission**	**Scope 1**	**Scope 2**
Technology	-0,004	-0,002	-0,004
	(0,056)	(0,002)	(0,039)
Telecom	-0,024	-0,151	0,020
	(0,065)	(0,175)	(0,039)
Health Care	-0,005	-0,012	-0,003
	(0,013)	(0,024)	(0,008)
Financials	-0,003	0,000	0,000

	(0,020)	(0,003)	(0,000)
Real Estate	0,000	0,014*	0,018
	(0,016)	(0,007)	(0,011)
Consumer Discretionary	-0,058*	0,019	-0,029
	(0,033)	(0,043)	(0,018)
Consumer Staples	0,004	0,002	0,036
	(0,091)	(0,086)	(0,030)
Industrials	0,014	0,006*	0,012
	(0,027)	(0,003)	(0,017)
Basic Materials	0,057	-0,004	0,005
	(0,081)	(0,138)	(0,036)
Energy	0,048	-0,015	0,012
	(0,148)	(0,026)	(0,013)
Utilities	-0,010	-0,141**	-0,004
	(0,016)	(0,065)	(0,006)
Return on Equity	0,398***	0,379***	0,395***
	(0,075)	(0,078)	(0,078)
Log Market Value	-52,659***	51,699***	52,502***
	(2,804)	(2,818)	(2,775)
Book-to-Market	10,605***	11,710***	11,163***
	(4,033)	(4,265)	(4,215)
Leverage	-10,091**	-9,903**	-9,920**
	(4,361)	(4,521)	(4,476)
Investment Rate	-31,479	-42,301	-42,853
	(57,366)	(60,031)	(59,663)
Log Property, Plant, Equipment	10,658***	9,968***	10,590***
	(1,804)	(1,938)	(1,944)
Sales Growth	0,073**	0,071**	0,068**
	(0,032)	(0,033)	(0,032)
Constant	333,372***	334,243***	332,974***
	(27,135)	(28,212)	(28,290)
Prob > F	0,000	0,000	0,000
Within R-Squared	0,325	0,326	0,328
Observations	2 679	2 576	2 581

Table 7. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

4.3 Non-Linearity – Section Three

The third section of the analysis investigates whether there is a non-linear relationship in the estimated carbon premium. By non-linear, I will test if the marginal premium increases as total emission increases. The test is conducted by regressing stock returns on Log Emission, including the first-difference estimator for the variable. *Table 8* presents the statistical output of the regression, with each column representing the variables for total-, scope 1- and scope 2 emissions.

Table for Hypothesis 3 - Non-linear Effects			
Variables	**(1)**	**(2)**	**(3)**
Log Carbon Emission	2,064		
	(1,855)		
First-Difference Log Total Emission	-1,714		
	(1,297)		
Log Scope 1 Emission		1,026	
		(2,223)	
First-Difference Log Scope 1 Emission		-0,298	
		(1,768)	
Log Scope 2 Emission			2,506
			(1,602)
First-Difference Log Scope 2 Emission			-0,107
			(1,699)
Return on Equity	0,328***	0,343***	0,342***
	(0,087)	(0,096)	(0,94)
Log Market Value	-62,191***	-63,645***	-64,449***
	(3,071)	(3,429)	(3,436)
Book-to-Market	12,386***	12,898***	12,523***
	(4,127)	(4,386)	(4,389)
Leverage	-10,481***	-10,769**	-10,080**
	(3,765)	(4,048)	(3,944)
Investment Rate	-77,001	-74,219	-53,564
	(66,213)	(72,092)	(70,813)
Log Property, Plant, Equipment	17,962***	17,452***	17,033***
	(2,238)	(2,509)	(2,469)
Sales Growth	0,051	0,045	0,039
	(0,033)	(0,035)	(0,035)
Constant	291,581***	325,214***	378,409***
	(46,112)	(49,171)	(49,369)
Prob > F	0,000	0,000	0,000
Within R-Squared	0,370	0,378	0,389
Observations	2 256	2 020	2 021

Table 8. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

The estimated panel regression did not indicate any statistically significant relationship between Log Emission and yearly returns when accounting for the first-difference estimator. Log Emission for all scopes is still positive and with a size close to the one found in section 4.1, but the relationship in not statistically proven. For the first-difference estimator, none of the scopes were deemed significant. However, the signs are negative, and a negative coefficient would imply that the marginal carbon premium decreases for an extra ton of carbon emissions. The coefficients and their sign create an interesting aspect. A possibility is that the signs are due to investors becoming complacent after emissions reach certain levels and accepting the firm's business model for what it is.

Nevertheless, the relationship is not statistically significant for either scope or when combined. However, given the limitations of years in the data sample, a relationship could potentially be formed with a larger dataset. The literature review does not refer to any evidence suggesting a non-linear relationship. Yet, when considering the effects emission could have on a firm's cash flows, there are components that could lead to this sort of relationship (see Chapter 2.1 for cash flow influence).

4.4 Carbon Intensity – Section Four

The final hypothesis tested investigates the relationship between carbon intensity and stock returns. As outlined in Chapter 3, efficient resource use can reduce exposure to transition risks and, consequently, carbon risk. Companies with a low carbon intensity ratio are deemed efficient, whereas those with a high ratio are considered less efficient. Therefore, we anticipate a positive coefficient, suggesting that less efficient firms are subject to a premium. The relevance of the carbon intensity ratio varies by industry but remains a critical measure used in research to assess carbon risk. Trinks et al. (2017) found that higher Carbon Intensity, indicating lower economic output per unit of emission, increases firms' equity cost of capital. The statistical results from the regression are detailed in *Table 7*.

Table for Hypothesis 4 - Carbon Intensity

Variables	**(1)**	**(2)**	**(3)**
Carbon Intensity Total Emission	0,00016***		
	(0,000)		
Carbon Intensity Scope 1 Emission		1,120	
		(0,859)	
Carbon Intensity Scope 2 Emission			-2,226
			(13,292)
Return on Equity	0,396***	0,423***	0,429***
	(0,074)	(0,081)	(0,080)
Log Market Value	-51,430***	-53,778***	-53,750***
	(2,715)	(2,918)	(2,909)
Book-to-Market	11,157***	10,053**	9,803**
	(3,895)	(4,060)	(4,057)
Leverage	-9,027**	-11,947**	-11,303**
	(4,261)	(4,742)	(4,637)
Investment Rate	-36,027	-19,677	-26,644
	(56,796)	(59,916)	(60,394)
Log Property, Plant, Equipment	10,440***	11,122***	11,210***
	(1,741)	(1,847)	(1,1862)
Sales Growth	0,068**	0,056*	0,056*
	(0,031)	(0,032)	(0,032)
Constant	324,487***	336,678***	335,579***
	(26,051)	(28,147)	(28,368)

Prob > F	0,000	0,000	0,000
Within R-Squared	0,322	0,339	0,337
Observations	2 717	2 543	2 541

Table 9. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

The statistical regression estimated our variable of interest, carbon intensity, to be significant at the 1% level. The estimated coefficient is measured at 0,00016, implying a positive relationship between carbon intensity and stock returns, aligning with the hypothesis. Interpretation of the estimated coefficient suggests that a one-unit increase in carbon intensity increases the yearly stock return by 0,00016 percentage points. As carbon intensity is measured as Metric Tonnes of Emission divided by total sales, the values are minimal, with the average in the sample being 0,16 (table 3).

To interpret the effect more easily, the coefficient is multiplied by 100. After multiplying the coefficient, the new value is 0,016. This means that a one-percentage-point increase in carbon intensity increases the yearly percentage return by 0,016 percentage points. As the value is deemed significant at the 1% level, there is a statistical relationship between carbon intensity and stock returns; however, the financial effect is relatively small.

Bolton and Kacperczyk (2021) analyzed the same variable, but their study did not find any evidence of carbon intensity having a relationship with stock returns. They argue that the measure is less relevant, as carbon intensity is a ratio, and that it is an inappropriate variable representing exposure to carbon risk. They further argue that firms and industries with similar levels of efficiency may exhibit significant variations in total emissions and not accurately represent the carbon risk an entity encounters.

While they argue that the ratio might be a subpar measure of exposure to carbon risk, research has utilized the variable in numerous studies and included it in the analysis to increase the robustness (Bolton & Kacperczyk, 2021, 2023; Trinks et al., 2017; J. Wang et al., 2021).

4.4.1 Industry Analysis

To overcome some of the criticism made by Bolton & Kacperczyk (2021) (regarding inappropriate variables and discrimination across firms and sectors), carbon intensity is also regressed against each industry individually by interacting the carbon intensity towards each industry identifier. *Table 10* presents the full statistical output from the industry regression.

Table for Hypothesis 4 - Carbon Intensity # Industry Dummy

Variables	Total Emission	Scope 1	Scope 2
Technology	-98,306	19,905	35,239

	(781,939)	(44,655)	(80,918)
Telecom	64,657	332,054	-267,485
	(72,805)	(473,949)	(183,434)
Health Care	62,306	-20,562	-41,887
	(134,309)	(67,636)	(27,354)
Financials	18,189**	3,697*	1,467
	(8,020)	(1,977)	(21,396)
Real Estate	-12,573	-10,550	-45,149
	(54,611)	(96,674)	(51,783)
Consumer Discretionary	1,461*	-7,521***	16,071
	(0,760)	(2,507)	(29,021)
Consumer Staples	5,462***	5,189	26,227
	(1,418)	(28,838)	(63,631)
Industrials	1,777	4,214	53,761
	(4,293)	(2,908)	(50,204)
Basic Materials	-6,067	-21,975	-66,452
	(10,835)	(13,741)	(64,279)
Energy	0,00016***	0,302	3,948
	(0,000)	(0,555)	(15,373)
Utilities	1,624	4,298	25,073
	(2,562)	(2,905)	(11,852)
Return on Equity	0,397***	0,427***	0,433***
	(0,075)	(0,081)	(0,079)
Log Market Value	-51,725***	-53,895***	-53,775***
	(2,720)	(2,850)	(2,889)
Book-to-Market	10,962***	9,861**	9,654**
	(3,973)	(4,066)	(4,071)
Leverage	-10,284**	-11,116**	-11,011**
	(4,374)	(4,751)	(4,664)
Investment Rate	-24,860	-21,872	-25,832
	(57,892)	(60,218)	(61,194)
Log Property, Plant, Equipment	11,029***	11,345***	11,321***
	(1,760)	(1,860)	(1,865)
Sales Growth	0,080**	0,056*	0,055*
	(0,032)	(0,033)	(0,032)
Constant	316,877***	334,371***	334,562***
	(26,708)	(28,374)	(28,651)
Prob > F	0,000	0,000	0,000
Within R-Squared	0,324	0,342	0,340
Observations	2 717	2 543	2 541

Table 10. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

Financials, Consumer Discretionary, Consumer Staples, and Energy are the industries presenting a statistically significant relationship between carbon intensity and stock returns. Energy has the same value as the generalized regression, while the other sectors have a much larger value. Due to the size of the coefficients, the interpretation will not include any multiplication.

The estimated coefficient implies that a one-unit increase in carbon intensity should increase the yearly return by 18,2% (Financials), 1,4% (Consumer Discretionary), or 5,4% (Consumer Staples). These values are substantially large, but considering that the average carbon intensity across the sample is 0,16 a one-unit increase in the measure is quite considerable. A more appropriate change would be 0,05. Such an increase would lead to either a 0,91% (Financials), 0,07% (Consumer Discretionary), or 0,27% (Consumer Staples) increase in yearly percentage return.

The result from the analysis is somewhat surprising, as few of the highest average emitting industries are deemed significant. Consumer Discretionary and Consumer Staples are in the middle when sorting by output of greenhouse gas emission, while Financials are in the bottom three (*table 2).* This could indicate that investors care less about efficiency for firms operating in a sector characterized by high emission output but incorporate the element for less emitting industries. Consumer Discretionary is the only sector showing statistical significance when regressing on an individual scope (scope 1). However, the coefficient changes sign and indicates no carbon premium on firms with lower internal efficiency of resource use (see discussion chapter 4.1.1 for discussion about change in coefficient sign).

Lastly, I want to remind the reader that all analyses regressed on the industry identifier are quite demanding given the data sample and that the limitations in the data must be considered when interpreting the statistical results.

4.5 EU Member Analysis – Section Five

The final element being controlled for in the analysis is whether membership in the Union has any impact on the estimated carbon premium. As discussed in Chapter 3.1, country-level data are retrieved for each entity in the sample. The sample consists of 17 nations, with three countries not being members of the EU. Even though there are potentially limited legislative differences between membership and not, the test is conducted to control for the possible variations. The countries excluded from the regressions are the United Kingdom, Switzerland, and Norway. *Table 11* presents the statistical output for all the regressions.

Table for EU Country Regression - All Carbon Measures

Variables	**1**	**2**	**3**	**4**
Log Total Emission	2,066		1,987	
	(2,300)		(2,784)	
Percentage Change Emission		-0,004		
		(0,010)		
First-Difference			-0,918	
			(2,885)	

Carbon Intensity				2,291
				(2,454)
Return on Equity	0,496***	0,489***	0,405***	0,498***
	(0,095)	(0,096)	(0,090)	(0,095)
Log Market Value	-52,194***	-53,368***	-63,098***	-52,131***
	(3,667)	(3,815)	(3,894)	(3,658)
Book-to-Market	7,581	7,096	9,146*	7,564
	(4,823)	(5,039)	(4,983)	(4,822)
Leverage	-7,739	-8,762	-16,981**	-7,678
	(5,948)	(6,067)	(6,859)	(5,951)
Investment Rate	-9,649	-5,529	-103,282	-3,346
	(75,347)	(75,981)	(82,335)	(75,512)
Log Property, Plant, Equipment	16,295***	16,626***	27,945***	16,397***
	(2,547)	(2,655)	(3,113)	(2,565)
Sales Growth	0,080*	0,077*	0,049	0,086*
	(0,045)	(0,045)	(0,046)	(0,045)
Constant	221,841***	253,809***	230,326***	244,246***
	(44,144)	(36,461)	(62,248)	(35,065)
Prob > F	0,000	0,000	0,000	0,000
Within R-Squared	0,324	0,324	0,390	0,324
Observations	1 702	1 675	1 413	1 702

Table 11. The dependent variable is the Yearly Return. All regressions include firm fixed effects for the sample period from 2017-2022. Robust Standard Errors are reported in parenthesizes below the coefficient.
** 10% Significance level, ** 5% Significance level, *** 1% Significance level*

When we remove the non-members from our estimation, we see a drastic reduction in the number of observations. The United Kingdom contains the highest number of firms included in the sample. When those observations are removed, the amount of data is limited (Switzerland is the fourth biggest contributor as well). The model statistics stay consistent with prior regressions, and all the coefficients remain the same sign.

The fascinating element to interpret from the panel regressions is that none of the measures for carbon risk are deemed statistically significant when removing the three countries. Previously, both Log Total Emission and Carbon Intensity were deemed statistically significant, but neither is when only analyzing membership countries. As mentioned, all coefficients remain the same sign. However, since the United Kingdom and Switzerland are such large contributors to the dataset, the relationship might be eradicated when removing those countries. Switzerland and the UK represent just above 1/3 of the whole dataset, and by removing such a large fraction, the existence of a statistical relationship between carbon risk and stock returns might also be eliminated. Nevertheless, it is an interesting observation, and exemplifies how large part the United Kingdom and Switzerland are of the European equity market.

5. Conclusion

In 2016, the establishment of the Paris Climate Agreement marked a pivotal shift, placing environmental issues at the forefront of global challenges. This shift has significantly influenced financial markets, with climate considerations increasingly shaping investor decisions. This dissertation builds on existing research, demonstrating that investors demand higher returns from companies with significant carbon emissions, reflecting the elevated risk associated with these investments. Unlike prior studies focusing on different markets and periods, this research contributes to the literature by examining the European financial market during a more present-day timeframe. By utilizing different proxies to capture carbon risk and conducting the study on the European equity market, the thesis has exposed various dimensions of the carbon risk premium hypothesis.

Consistent with previous research, I find significant evidence that stock returns are related to the total output of greenhouse gas emissions. By increasing the total output of greenhouse gas emissions, a firm will increase its risk exposure, and investors will demand a higher return (the carbon premium). The estimated results indicate a strengthened relationship compared to prior literature on different markets. While the study investigates the same relationship and results are highly comparable, differences in the frequency of data points and utilization of estimation techniques must be considered when making the comparison.

On the other hand, Yearly Changes in carbon emissions were not deemed statistically significant. The result differs from the literature, where Total Output and Yearly Change were both statistically significant. While the results are surprising, they may be a function of the differences in the frequency of observations and the limited dataset.

To further investigate the effect carbon emissions have on stock returns and the characteristics of the estimated premium, a first-difference estimator was employed to control for non-linearity in the data. The regression yielded a negative sign for the coefficient, suggesting that the marginal carbon premium decreases as total emission increases. The coefficient was not statistically significant, but the relationship might require a larger dataset.

The last measure tested to control for carbon risk was carbon intensity. The measure was calculated by dividing total sales over total emissions and used to capture the related transition risk for inefficient firms. Although the results were deemed statistically significant, the coefficient has a minimal value and is not deemed economically significant. This suggests that transition risk is a critical aspect of carbon risk for high-emitting firms, although the choice of variable could have been better optimized.

5.1 Limitations

Although the data and financial variables in this analysis have been carefully selected based on their ability to predict stock returns, we cannot assume that we have captured all elements affecting stock returns. Stock returns are a volatile measure, influenced by much noise besides the intrinsic value of a firm. Considering the long time between our observations, possible events within each observation affect our results. As explained in Chapter 3.1, more stringent measures in reporting emissions will be implemented from 2024 onwards. This will likely increase the transparency between an entity's emissions and public databases, creating a higher frequency of data points.

The second element under consideration is also related to data availability. However, this is not related to the frequency of data points but is instead connected to accuracy and complete reporting. This thesis utilizes Scope One and Two as the proxy for total emission. However, as explained in Chapter 3.3, there are more Scopes to consider. Due to the third scope's lack of good estimation techniques and no reporting from entities in the sample, a considerate aspect of carbon emission is not included.

5.2 Further Research

Given the subject's dynamic nature influenced by ongoing political interventions, there is plenty of scope for further research. Additional investigation is advised once data becomes transparently available at all levels. A subsequent industry analysis should also be conducted, utilizing a more comprehensive and valid dataset. By adopting a global perspective rather than concentrating solely on one political region and employing a risk characteristic method in place of the firm characteristic method used in this study, potentially insightful discoveries could be uncovered.

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Appendix

1. Stata Script for Regressions

Setting the Panel: xtset ID Year

Regression: reghdfe RET(*Dependent variable)* – Variable of interest (*Carbon Risk Proxy)* **-** ROE LogSize BM Leverage IR LogPPE SalesGR*(Control Variables)*, **-** absorb(ID)*(Fixed effect)* **-** vce(robust)*(Robust Standard Errors)*

2. Mathematical explanation of numerical interpretation for natural logs

Log for different values

Initial log emission (1 000 000) = 13,82

Final log emission (1 100 000) = 13,91

Differences in log emission

Delta Log (*E)* = 13,91 – 13,82 = 0,09

Applying coefficient

<u>Increase in yearly return = Log Coefficient (2,52) * 0,09 ≈ 0,225 Percentage points</u>

3. Mathematical explanation for 1 standard deviation increase in carbon emission

New log value:

Mean log + Standard deviation = 11,88 + 2,73 = 14,61

Difference in log value

Delta log = CO2Log Standard deviation of 2,73

Apply the coefficient to find the change in yearly returns.

2,52 * 2,73 = 6,88

Changes in yearly returns

<u>Increase in yearly returns one standard deviation = Coefficient 2,52 * Delta Log ≈ 6,88 Percentage Points</u>