Climate change and investment portfolios: Is there a green systematic risk factor?

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I sincerely appreciate my friends and family's love and support throughout this process. I wouldn't have been able to finish this journey without their encouragement and motivation.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Universidade do Minho, 29 de maio de 2023

(Daniela Alexandra Figueiredo Mendes)

Alteração climática e portfolios de investimentos: será que existe um fator verde de risco sistemático?

Resumo

O objetivo desta dissertação é avaliar o desempenho de carteiras Europeias com diferentes níveis de pegada carbónica e perceber se o risco climático, medido pelas emissões de carbono das empresas, representa um fator de risco sistemático.

Para isso, foram selecionadas empresas constituintes do STOXX600 da Europa, de modo a construir duas carteiras (cada uma delas na versão igualmente ponderada e ponderada pelo valor): uma com as 50 empresas mais poluentes, e outra com as 50 empresas menos poluentes. A diferença de rendibilidades entre a carteira green e poluente representa o fator Green Minus Polluter (GMP).

Numa primeira análise, avaliou-se o desempenho e a exposição ao risco das carteiras verdes e das carteiras poluentes, de modo a compreender se as rendibilidades das carteiras são explicadas por modelos considerados standard na área da avaliação do desempenho. Os resultados obtidos revelam que o modelo de Carhart (1997) tem um alto poder explicativo no que toca retornos às rendibilidades em excesso s das carteiras (poluente e não poluente). No que toca ao desempenho das carteiras, quer a poluente quer a não poluente (cada uma delas na versão igualmente ponderada e ponderada pelo valor) apresentam rendibilidades anormais positivas. Podemos também concluir que, no geral, ambas as carteiras são sensíveis a todos os fatores de risco utilizados.

Posteriormente, foi realizada uma análise de asset pricing , correndo uma regressão em painel e utilizando um novo fator de risco: o fator GMP, para avaliar se este fator era significativo no que toca a explicar as rendibilidades de uma carteira de ações. Os resultados indicam que o fator de risco associado às emissões de carbono tem impacto nas rendibilidades em excesso do STOXX 600 da Europa, demonstrando que os investidores exigem um prémio de risco superior quando investem em empresas com emissões de carbono mais altas, consistente com este ser um fator de risco sistemático.

Palavras chave: risco de carbono, performance do portfolio, Green Minus Polluter, avaliação de ativos

Climate change and investment portfolios: Is there a green systematic risk factor?

Abstract

The aim of this dissertation is to evaluate the performance of European portfolios with different levels of carbon footprint and assess whether climate change, proxied by companies' carbon emissions, represent a systematic risk factor on investment portfolios.

To do that, companies from the Euro STOXX600 were selected, in order to construct two portfolios (each one in its equal-weighted and value-weighted version): one with the 50 most polluting companies and the other with the 50 less polluting, or greenest ones. The difference in returns between the green and polluter portfolio represents the Green Minus Polluter (GMP) factor.

In a first analysis, I evaluated the performance and risk exposure of the Green and the Polluter portfolios to assess if the excess returns of these portfolios are explained by models considered standard in the portfolio evaluation area. The results obtained show that the Carhart (1997) has a high explanatory power when it comes to explaining the excess returns of the portfolios. Regarding portfolio performance, both the equally weighted and value weighted Green and Polluter portfolios present positive abnormal returns. One can also conclude that, in general, both portfolios are sensitive to all risk factors used.

The next step was to perform an asset pricing analysis, to investigate if the GMP factor is significant when it comes to explaining excess returns of a portfolio of stocks. I concluded that the carbon risk factor is being priced on the excess returns of the Europe STOXX600, showing that investors demand a higher risk premium when holding on to firms with higher carbon emissions consistent with this factor being systematic risk factor.

Key words: carbon risk, portfolio performance, Green Minus Polluter, asset pricing

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1. Introduction

In the aftermath of the Paris Agreement in 2015, the carbon footprint associated to companies' activities has been in the spotlight, with many companies moving towards more environmentally friendly practices. The urge to combat climate change has been gaining consensus all over the world, and there is a growing awareness that achieving climate goals requires aligning finance with sustainability (Monasterolo, 2020). In financial markets, the asset management industry is also recognizing the importance of integrating climate risks into the portfolio management process (Alok et al., 2020; Krueger et al., 2020). For instance, one of the major asset management companies – Blackrock - states that "integrating sustainability can help investors build more resilient portfolios and achieve better long-term, risk-adjusted returns"1. Regulators are also paying attention to this issue. In 2015, The Task Force on Climate-Related Financial Disclosures (TCFD) was created by the Financial Stability Board (FSB). The aim of TCFD was to provide investors and other economic agents with climate-related information affecting financial risks. In Europe, the Sustainable Financial Disclosure Regulation, in force since 2021, has also introduced additional requirements regarding the disclosure of funds' sustainability risks. Altogether, these efforts reflect the increasing awareness of the impact of climate risks in the economy and in financial markets.

In light of these developments, a recent issue of debate among investors and academics relates to the impact of climate change in asset prices (Bolton & Kacperczyk, 2021). While an established literature aims to explain the cross-section of stock returns based on the market and exposures to aggregate risk factors proxied by observable firm characteristics such as size, value and momentum, a flourishing set of studies address whether climate change, represented by variables related to carbon emissions, represents an extra source of systematic risk. Several recent studies, such as Bolton and Kacperczyk (2021) and Görgen et al., (2020), and Hsu et al., (2022) find contrasting results. While Bolton and Kacperczyk (2021) and Hsu et al. (2022) find that portfolios of stocks with higher climate risks obtain higher returns and document the existence of a carbon premium, Görgen et al. (2020) is not supportive of climate risks being priced in financial markets. The aim of this study is to analyse the impact that carbon risk can have on portfolio returns, answering empirically to the following question: "Does climate change exposure represent a systematic risk factor in

[1] : https://www.blackrock.com/corporate/investor-relations/2021-blackrock-client-letter

investment portfolios?” To answer this question, I will form a proxy for climate change risk: the green minus polluter (GMP) factor, inspired by Gimeno and Gonzalez (2022). The GMP factor is formed for the European stock market over the period between 2010-2020. Then, I will evaluate the performance of portfolios formed on this factor, using the well-known Carhart (1997) model. Furthermore, I analyse whether this factor is useful in explaining excess returns, using a data panel regression approach.

This dissertation is organized as follows: in the next section I will discuss the relevant literature regarding theoretical arguments suggesting a relationship between carbon emissions and stock returns. The methodology section explains in detail the methods used to conduct this study. In the data section I describe the date used in the empirical analysis. The following section in the results, where I discuss the results obtained when analyzing the data. In the last section, I write some conclusions about the study conducted.

2. Literature Review

The impact of carbon risk on stock returns has become an important area of research. as investors and policymakers seek to understand the implications of climate change for financial markets. Indeed, the significance of climate risks for institutional investors is addressed by Krueger et al. (2020). Their study concluded that "investors consider climate risks as important investment risks" and that institutional investors are also actively managing climate risks as they become increasingly conscious of their significance. By incorporating climate risk analyses into their investment strategies and interacting with businesses to encourage climate-related disclosures, the authors advise institutional investors to take a proactive approach to mitigating climate risks. In this literature review, I examine some papers that explore the relationship between carbon risk and stock returns.

Pástor et al. (2021) develop a model to explain the returns of green assets. According to the model, the fact that green assets have a higher demand compared to brown assets along with the hedging they provide against climate change implies that they will provide lower expected returns. However, it is important to note that Pástor et al. (2021) further explain that it is possible for green assets to outperform in periods where there is an unexpected shift in consumers' and investors' tastes towards green assets.

Several empirical studies explore this issue. For instance, Bolton & Kacperczyk (2021) and Hsu et al. (2022) find that portfolios of stocks with higher climate risks obtain higher returns and document the existence of a carbon risk premium. Furthermore, in line Pástor et al. (2021), there are also studies that document higher returns of green stocks when there is a shift of investors' tastes towards greens. This is the case of Ardia et al. (2022) and Pástor et al. (2022), who observe that green stocks outperform brown stocks when there are greater concerns about climate change and environmental issues. This happens because investors are increasingly transitioning their investments from high carbon emission companies to environmentally friendly ones as they become more aware of global warming, which will cause green stocks to outperform the brown ones (Choi et al., 2020).

However, there are contrasting results regarding the impact of a climate risks. For instance, the results of Görgen et al. (2020) are not supportive of climate risks being priced in financial markets, with the authors stating that "these results are inconsistent with expectations that brown firms command a positive risk premium" (Görgen et al., 2020, p.24).

In their study, Görgen et al. (2020) examine the idea of carbon risk and how it affects businesses engaged in emissions-intensive sectors. They contend that as market pressures pushes for further emissions reductions, businesses that do not effectively manage carbon risk run the risk of suffering financial losses. This paper also integrated a carbon-related risk factor, the Brown-Minus-Green, that is built by forming a portfolio that is long on brown stocks and short on green stocks. They conclude that this extra factor explained undiversifiable risk that affects returns, but found no evidence of a carbon risk premium. There are many explanations for why carbon risk does not appear to be valued, including the challenge that investors face in predicting and quantifying it. This suggests that, as some other articles find out (Midttun & Gjengedal, 2019), we are likely dealing with a problem of mispricing, which leads to the conclusion that carbon footprint should be taken into account as a risk factor in future pricing models.

Alessi et al. (2021, p. 8) found out that "a negative greenium indicates that investors accept lower compensation, ceteris paribus, to hold assets that correlate positively with the greenness and transparency factor", which means that investors demand a risk premium for investing in polluting stocks. Their study is based on a measure of companies' greenhouse gas emissions and environmental disclosures, which is used to develop a factor that measures environmental performance. They document that "investors buy stocks of greener and more transparent firms accepting a ceteris paribus lower return, as a hedging strategy to reduce their exposure to climate risk" (Alessi et al., 2021, p. 12).

Also, Bernardini et al. (2019) investigate the impact of carbon risk on stock returns in the European electric utilities sector. They develop a factor accounting for carbon risk exposure (Low-Minus-High), constructing a long-short portfolio that takes a long position in the Low Carbon portfolio and a short position in the high carbon portfolio. They discover that companies with higher carbon risk exposure suffer larger stock-return losses. This suggests that it is important for investors to account for carbon risk when making investment decisions, particularly in industries that are highly exposed to climate change.

Oestreich et al., (2015) also create a risk factor based on the emissions and carbon intensity of a firm (Dirty-Minus-Clean), which is a portfolio that presents the expected excess returns of a dirty portfolio minus the expected excess returns of a green one. They found negative correlation between stock returns and carbon emissions. This indicates that the higher the emissions, the lower the stock returns, which means that investors are considering companies' carbon risk exposure when making their investment decisions. This enhances the fact that investors should make investment decisions that reflect their concerns about climate changes, using carbon emission data to identify which companies are more exposed to carbon risk.

Rostad & Myking (2020) made their contribution to this topic by exploring the impact of climate change transition risk, showing that the coefficient of the carbon risk factor is statistically significant, suggesting that this new risk factor is helpful in explaining variations of risk-adjusted returns.

This literature review enhances how important it is to considering carbon risk when making investment decisions. All of the papers mentioned above demonstrate that investors should use information about climate risk exposure to make smart investment decisions, despite the fact that there are challenges associated with carbon risk and environmental disclosures.

3. Methods

The aim of this section is to describe the methodology to be applied in order to understand the effects of carbon risk on portfolio performance and whether carbon footprint should be considered a systematic risk factor. In this analysis, I start by addressing the formation of portfolios with different levels of carbon footprint. Then, I present standard performance evaluation models that will be used to evaluate the performance of the green and polluter portfolios. Finally, I will explore the effect of climate change, measured by the GMP factor, in a panel regression on expected stock returns.

3.1. The GMP factor and portfolio formation

There are different ways to proxy for climate change, and different studies have used different proxies for the climate risk factor (Venturini, 2021). I follow Gimeno and Gonzalez (2022) and form the GMP (Green-Minus-Polluter) as a proxy for carbon risk. The GMP factor is formed based on companies' carbon emissions. The procedure consists of selecting companies from a market index – the Europe STOXX 600 – and sorting them accordingly to their carbon footprint. Because carbon footprint is typically higher in high production volume firms, those carbon emissions will be adjusted by the companies' revenues. The 50 stocks with the lowest carbon footprint are classified as green stocks and the 50 stocks with the highest carbon footprint are classified as the polluting ones. Once the companies are classified as green and polluters, the next step is to build equally-weighted and value-weighted portfolios composed by 50 green companies and 50 polluting companies. Furthermore, I form the Green Minus Polluter portfolio, which is a portfolio that represents a strategy of going long on the green portfolio and short on the polluter.

3.2. Portfolio performance evaluation models

Portfolio performance is evaluated following the alpha based on the Carhart (1997) four factor model, which considers the market, size, book-to-market ratio and momentum factors to explain the excess returns of the portfolios mentioned previously. This model, which is considered standard in the literature, is expressed as:

$$r_{p,t} - r_{f,t} = \alpha_p + \beta_1(r_{m,t} - r_{f,t}) + \beta_2 SMB_t + \beta_3 HML_t + \beta_4 MOM_t + \mathcal{E}_{p,t} \quad (1)$$

where $(r_{p,t} - r_{f,t})$ represents the excess return of the portfolio, $(r_{m,t} - r_{f,t})$ is the excess return of the market, SMB_t is the factor that represents the return of a portfolio composed by small stocks minus the return of a portfolio composed by big stocks, HML_t is the factor that represents the return of a portfolio composed by high book-to-market stocks minus the return of a portfolio composed by low book-to-market stocks and MOM_t refers the momentum factor, which captures the tendency of winning stocks to proceed to perform well in the future (it is considered as the "persistence" factor). $\mathcal{E}_{p,t}$ is the residual with mean zero and β_1, β_2, β_3 and β_4 are the factor exposures of the portfolios.

3.3. Asset Pricing Analysis

The last part of the methodology aims to evaluate the effect of the GMP factor on the expected stock excess returns. For this purpose, I will follow a panel regression approach, as in Alessi et al. (2021).

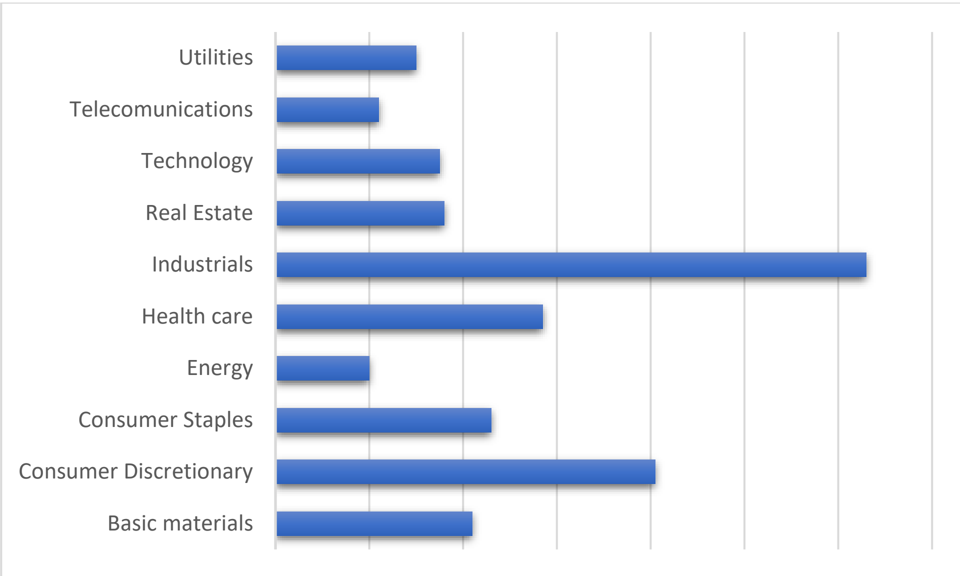
To simplify the process, I follow the procedure of Black et al. (1973) and group stocks into portfolios. Specifically, I group the stocks of the Stoxx600 Index into ten portfolios. Portfolio 1 is formed from the 10% stocks of the index with the highest betas and portfolio 10 is formed from the 10% stocks with the lowest betas. Each portfolio was composed by approximately 40 companies. Then, a panel regression analysis is performed, where the dependent variable is the STOXX 600 excess returns and the independent variables are the market excess returns, the SMB, the HML, the MOM and the GMP.

4. Data

4.1. The European stock market

To implement the empirical analysis, I collected, from Refinitiv Eikon Datastream, the constituents of the European STOXX 600. I identified all 600 constituents of the index and excluded the financial companies. As Gimeno and Gonzalez (2022) argue, the companies from the financial sector typically have a very low carbon footprint, so including them would lead to potential compounding effects of the green factor with the financial factor. After removing the financial companies, there were 495 stocks left. Figure 1 presents the sectors to which these companies belong. As one can observe, most companies are from the industrials sector.

Figure 1: Industry composition

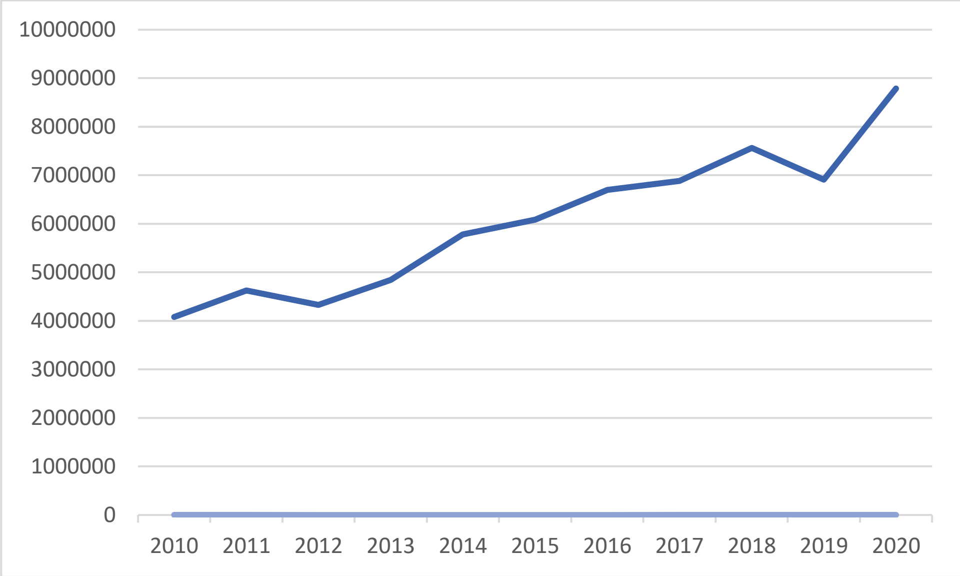


This figure reports the industry composition per sector of the 495 stocks selected from the Euro STOXX 600. The industries from the financial sector were excluded.

As one can see, the main industry in the companies selected from the euro STOXX 600 is the industrial, followed by consumer discretionary and health care.

Figure 2 presents the evolution of total market capitalization of these companies (in €) throughout the years, from 2010 to 2020:

Figure 2: Total market capitalization (€) per year



This figure reports the total market capitalization of the 495 stocks selected from the Euro STOXX 600 from January 2010 to December 2020. The industries from the financial sector were excluded.

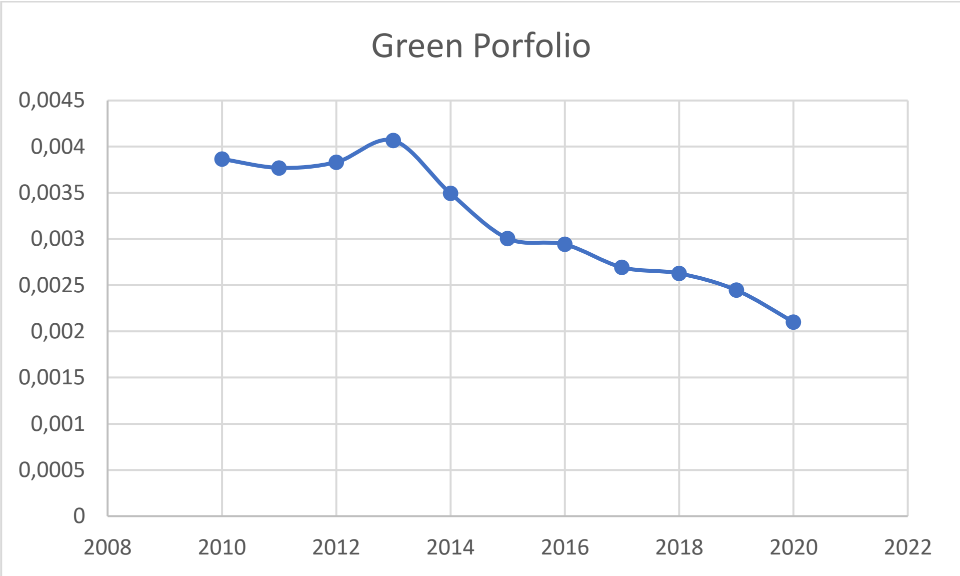
This figure shows that the total market capitalization increases in this 10-year period, growing more than 100% from 2010 to 2020.

4.2. The Green and Polluter Portfolios

The Green and Polluter portfolios were formed based on companies' carbon emission intensity, in a procedure similar to Gimeno and Gonzalez (2022). For this purpose, I retrieved from Refinitive Datastream annual data on carbon emissions (CO2 Equivalents Emission Direct) disclosed (scope 1) for the constituents of the Euro Stoxx 600 (excluding financial companies), as Bernardini et al. (2019) and Görgen et al. (2020). From this database, I also collected data on companies' revenues in 2020. The revenues were collected with the purpose of adjusting emissions to the company's profitability. The next step was to divide the carbon emissions of each company by its revenues, and rank companies by the ratio of carbon emissions to revenues. A high (low) coefficient means that a company is a more (less) polluter. Throughout this process some companies were excluded since they did not present data on carbon emissions for the majority of the years. The polluter portfolio comprises the 50 companies with the highest ratio of carbon emissions, while the green portfolio comprises the 50 companies with the lowest ratio of carbon emissions. In figures 3 and 4 I can see the evolution of the average coefficients (CO2 Equivalents Emission Direct / Net Sales or

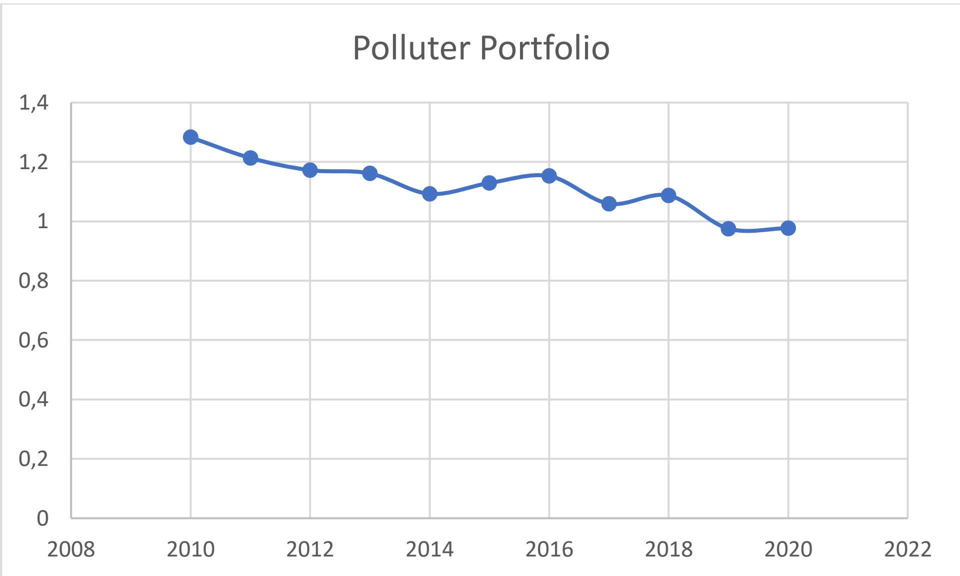
Revenues) over time, for the green and for the polluter portfolios. As it can be observed, the coefficient in both the green and the polluter portfolios decreases over time, possibly due to the awareness concerning climate crisis.

Figure 3: Evolution of the ratio carbon emissions/revenues of the green portfolio



This figure reports the evolution of the carbon emissions/revenues ratio from January 2010 to December 2020 for the green portfolio. The green portfolio was composed by the 50 companies with the lowest ratio.

Figure 4: Evolution of the ratio carbon emissions/revenues of the polluter portfolio



This figure reports the evolution of the carbon emissions/revenues ratio from January 2010 to December 2020 for the polluter portfolio. The polluter portfolio was composed by the 50 companies with the highest ratio.

4.3. Portfolio returns and risk factors

After defining which companies belong to the green and to the polluter portfolio, the next step consisted in collecting, from Refinitiv Datastream, the return indexes for those companies from January 2010 to December 2020, encompassing a total of 132 months. Then, I formed the portfolios and constructed the Green Minus Polluter factor. This factor represents the differences in returns between the Green portfolio and the polluter portfolio, thereby representing an investment strategy of going long on the green portfolio and short on the polluter one. Monthly total return indexes of all companies were retrieved from Refinitiv Eikon DataStream, in Euros. With this information, I was able to calculate the discrete returns for each stock:

$$R_{i,t+1} = (RI_{i,t+1} - RI_{i,t})/RI_{i,t} \tag{2}$$

where $R_{i,t+1}$ is the return of stock *i* in period *t+1* and $RI_{i,t+1}$ is the total return index of stock *i* in the same period. Next, I formed equally-weighted and value-weighted portfolios for both the green and the polluter firms. In this case, the market value monthly data of each firm was retrieved from Refinitiv Datastream to calculate the weight each stock had in the total market value (for each month).

Table 1: Descriptive statistics of the green and polluter portfolios

Descriptive Statistics	Green	Polluter
Nº Observations	132	132
Minimum	-8.65%	-14.10%
Maximum	14.35%	21.11%
Mean	1.29%	0.80%
Median	1.29%	1.19%
Variance	0.13%	0.21%
Standard Deviation	3.64%	4.58%
Skewness	0.023	0.283
Kurtosis	0.991	2.810
Jarque-Bera test p-value	0.102	0.000

This table reports the descriptive statistics (monthly excess returns) of the green and polluter portfolios from January 2010 to December 2020. The sample is composed by 132 observations.

Table 1 presents the descriptive statistics of the green and polluter portfolios. As we can see in the previous table, there is a total of 132 observations corresponding to monthly excess returns from January 2010 to December 2020. The standard deviation is higher in the polluter portfolio. When it comes to the Jarque-Bera test for the p-value, the Polluter portfolio rejects the null hypothesis of the data following a normal distribution, whereas in the case of the green portfolio I cannot reject the normality hypothesis.

To run the regressions, I considered the excess returns of the green and polluter portfolios as well as their difference portfolio (GMP) as the dependent variable, considering the market excess returns, SMB, HML and MOM as the explanatory variables. Monthly data on these risk factors, as well as the risk-free rate, was extracted from Professor Kenneth R. French's data library website (European factors) and then converted to Euros. The regressions were computed in R Studio.

4.4. Data for Asset Pricing analysis

In order to understand if the carbon risk is priced, I will use the GMP factor, as well as other commonly used factors (the Mrk-rf, SMB, HML and MOM) to explore the excess returns of the STOXX600 Europe. Once again, financial companies were deleted from the analysis. Monthly data about total returns was extracted on the STOXX 600 Index. To compute the excess returns, I used the formula (2) and then subtracted the risk-free rate for each month.

The next step was to divide the stocks into 10 portfolios according to its betas, as mentioned previously in the methodology section. To do so, I calculated the betas for each stock against the market, using the European market excess returns as the market factor. Those excess returns were retrieved from Professor Kenneth R. French's data library website. Some betas could not be calculated, as there was missing data on the returns for some companies. A total of 406 stocks were left.

The following procedure was to create 10 portfolios (P1, P2, P3, P4, P5, P6, P7, P8, P9 and P10) – of roughly 40 stocks each – according to its betas, grouping them from the highest betas (P1) to the lowest betas (P10). Then, in order to execute the panel regression, I had to group the information on the date, the portfolio excess returns, the market excess returns, the SMB, HML, MOM and GMP for each one of the 10 portfolios. That resulted on 132 monthly observations for P1, followed by 132 monthly observations for P2, and so forth, ending with 132 monthly observations for P10.

5. Empirical results

In this section, the results of the empirical study will be presented and discussed. This section will start by analyzing the performance of the Green, Polluter and Green Minus Polluter portfolios, considering the Market, SMB, HML and MOM as the explanatory variables. After that analysis, I will proceed to carry out an asset pricing analysis, to observe if there is a carbon risk premium associated with stock returns.

5.1. The performance and risk exposures of the Green, Polluter and Green Minus Polluter Portfolios

I start by analyzing the performance of the green and the polluter portfolios, as well as that of the GMP portfolio. This investigation has into consideration the factor exposures of the portfolios, in order to understand if they capture the risk factors assumed in this analysis.

Tables 2 and 3 present the results of the Carhart (1997) four-factor model regressions on our three portfolios, considering equally-weighted and value-weighted portfolios, respectively.

Table 2: The performance of green, polluter and GMP portfolios - Equally weighted portfolios

	(GREEN-RF)		**(POLLUTER-RF)**		**(GMP-RF)**	
Predictors	*Estimates*	*p-value*	*Estimates*	*p-value*	*Estimates*	*p-value*
Intercept	0.007	<0.001***	0.006	<0.001***	0.001	0.543
Mkt-rf	0.787	<0.001***	0.843	<0.001***	-0.055	0.215
SMB	-0.446	<0.001***	-0.457	<0.001***	0.013	0.882
HML	-0.521	<0.001***	-0.232	<0.016**	-0.291	<0.001***
MOM	-0.314	<0.001***	-0.503	<0.001***	0.187	<0.001***
Observations	132		132		132	
R^2 / R^2 adjusted	0.776 / 0.759		0.781 / 0.774		0.433/ 0.415	

This table reports the estimates and the p-values of each risk factor and its estimates. These outputs are the result of a regression computed on the excess returns of the Green, Polluter and Green Minus Polluter (GMP) portfolios (considering the equally weighted portfolios), with the explanatory variables being the Market excess returns, Small-Minus-Big, High-Minus-Low and Momentum. The observations are monthly data retrieved related to excess returns, from January, 2010 to December, 2020. Note: The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level, respectively. Standard errors are corrected for heteroscedasticity and autocorrelation by following Newey and West (1987).

Table 3: The performance of green, polluter and GMP portfolios - Value weighted portfolios

	(GREEN-RF)		**(POLLUTER-RF)**		**(GMP-RF)**	
Predictors	*Estimates*	*p-value*	*Estimates*	*p-value*	*Estimates*	*p-value*
Intercept	0.008	<0.001***	0.006	<0.001***	0.002	0.426
Mkt-rf	0.797	<0.001***	0.772	<0.001***	0.026	0.584
SMB	-0.635	<0.001***	-0.729	<0.001***	0.097	0.353
HML	-0.506	<0.001***	-0.086	0.314	-0.422	<0.001***
MOM	-0.248	<0.001***	-0.325	<0.001***	0.077	0.187
Observations	132		132		132	
R^2 / R^2 adjusted	0.835 / 0.830		0.784 / 0.777		0.331/ 0.310	

This table reports the estimates and the p-values of each risk factor and its estimates. These outputs are the result of a regression computed on the excess returns of the Green, Polluter and Green Minus Polluter portfolios (considering the value-weighted portfolios), with the explanatory variable being the Market excess returns, Small-Minus-Big, High-Minus-Low and Momentum. The observations are monthly data retrieved related to excess returns, from January, 2010 to December, 2020. Note: The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level, respectively. Standard errors are corrected for heteroscedasticity and autocorrelation by following Newey and West (1987).

Starting with the equally weighted portfolios (outputs shown in table 2), the model has a reasonable explanatory power (r-squared) when it comes to explain the excess returns. The R^2 for the green portfolio is 77.6% and for the polluter is 78.1%.

As to portfolio performance, both portfolios present a positive and statistically significant alpha, indicating positive abnormal returns. The alpha of the GMP portfolio is insignificant, indicating no statistically significant differences between the green and the polluter portfolio.

Both the green and the polluter portfolios are sensitive to the market, as this factor is statistically significant at the 1% level both for the Green and for the Polluter portfolios. The results of the GMP portfolio indicate no statistically significant difference in the systematic risk of the green and polluter portfolio.

Regarding the size factor, the green and the polluter portfolios are more exposed to large companies, as the SMB coefficient is negative and statistically significant. The coefficient of the GMP portfolio is insignificant, indicating that there are no differences in both portfolios regarding exposition to the size factor.

In what concerns the value factor, the green and the polluter portfolios show a negative and statistically significant coefficients at the 1% and 5% level, respectively, indicating that these portfolios are exposed to growth stocks. Moreover, The HML coefficient of the GMP portfolio is negative and statistically significant, indicating that the green portfolio is more exposed to growth stocks than the value portfolio.

The results on the momentum factor show that both portfolios are negatively exposed to stocks with poor recent performance, presenting a statistically significant coefficient at the 1% level. The coefficient of the GMP portfolio indicates that the polluter portfolio is more exposed to poor recent performing stocks than its green counterpart.

Moving on to the value weighted portfolios (outputs shown in table 3), the model has a reasonable explanatory power (r-squared) when it comes to explain the excess returns. The R^2 for the polluter portfolio is 83.5% and for the polluter is 78.4%.

Considering portfolio performance, the results are similar to those of equally weighted portfolios: both portfolios present a positive and statistically significant alpha, indicating positive abnormal returns. Additionally, the alpha of the GMP portfolio is insignificant, indicating no statistically significant differences between the green and the polluter portfolio.

As to the market factor, it is statistically significant at the 1% level for both the Green and the Polluter portfolios. The results of the GMP portfolio show that there is no statistically significant difference in the systematic risk of the green and polluter portfolio.

The SMB coefficient, which accounts for the size factor, is negative and statistically significant, indicating that the green and the polluter portfolios are more exposed to large companies. The GMP portfolio's coefficient is negligible, showing that there are no differences between the two portfolios' exposition to the size factor.

The green portfolio exhibits a negative and statistically significant coefficient (at the 1% level), for the value factor demonstrating that it is exposed to growth stocks. The green portfolio is more exposed to growth stocks than the polluter portfolio, as shown by the negative and statistically significant HML coefficient (at 1% level) of the GMP portfolio.

The results on the momentum factor show that both portfolios are exposed to stocks with poor recent performance, (there is a negative and statistically significant coefficient at the 1% level). The coefficient of the GMP portfolio is insignificant, indicating that there are no differences in both portfolios regarding the exposition to the momentum factor.

5.2. Portfolio performance in sub-periods

The next step is to analyze how portfolio performance evolved in the most recent years compared to the first years. This analysis is motivated by several studies (e.g., Ibikunke & Steffan, 2017, Cortez et al., 2022) that find an improvement in the performance of green assets over time. For this purpose, I divided the full period into two sub-periods, in order to shed light on the evolution of green and polluter portfolios' abnormal returns over time. This analysis was performance using the value-weighted portfolios, considering that the R2 of the green and polluter portfolios in the regressions in the previous sections were higher.

Table 4 shows the performance of the Green, Polluter and GMP portfolios, considering value-weighted portfolios, for the first sub-period (from January 2010 to December 2015). Table 5 shows the performance of the Green, Polluter and GMP portfolios, considering value-weighted portfolios, for the second sub-period (from January 2016 to December 2020).

Table 4: The performance of green, polluter and GMP portfolios – Value weighted portfolios – from 2010 to 2015

	(GREEN-RF)		(POLLUTER-RF)		(GMP-RF)	
Predictors	*Estimates*	*p-value*	*Estimates*	*p-value*	*Estimates*	*p-value*
Intercept	0.008	<0.001***	0.004	0.172	0.004	0.128
Mkt-rf	0.730	<0.001***	0.764	<0.001***	-0.034	0.609
SMB	-0.674	<0.001***	-0.692	<0.001***	0.018	0.890
HML	-0.445	<0.001***	-0.188	0.123	-0.268	0.015**
MOM	-0.095	0.072*	-0.249	0.005***	0.154	0.038**
Observations	72		72		72	
R^2 / R^2 adjusted	0.815 / 0.804		0.793 / 0.781		0.268/ 0.224	

This table reports the estimates and the p-values of each risk factor and its estimates. These outputs are the result of a regression computed on the excess returns of the Green, Polluter and Green Minus Polluter portfolios (considering the value-weighted portfolios), with the explanatory variable being the Market excess returns, Small-Minus-Big, High-Minus-Low and Momentum. The observations are monthly data retrieved related to excess returns, from January, 2010 to December, 2015. Note: The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level, respectively. Standard errors are corrected for heteroscedasticity and autocorrelation by following Newey and West (1987).

Table 5: The performance of green, polluter and GMP portfolios – Value weighted portfolios – from 2016 to 2020

	(GREEN-RF)		(POLLUTER-RF)		(GMP-RF)	
Predictors	*Estimates*	*p-value*	*Estimates*	*p-value*	*Estimates*	*p-value*
Intercept	0.009	<0.001***	0.008	0.018**	-0.001	0.875
Mkt-rf	0.838	<0.001***	0.830	<0.001***	0.006	0.914
SMB	-0.628	<0.001***	-0.863	<0.001***	0.248	0.091
HML	-0.527	<0.001***	0.041	0.691	-0.567	<0.001***
MOM	-0.328	<0.001***	-0.287	0.008***	-0.044	0.631
Observations	60		60		60	
R^2 / R^2 adjusted	0.883 / 0.874		0.799 / 0.784		0.457/ 0.481	

This table reports the estimates and the p-values of each risk factor and its estimates. These outputs are the result of a regression computed on the excess returns of the Green, Polluter and Green Minus Polluter portfolios (considering the value-weighted portfolios), with the explanatory variable being the Market excess returns, Small-Minus-Big, High-Minus-Low and Momentum. The observations are monthly data retrieved related to excess returns, from January, 2016 to December, 2020. Note: The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level, respectively. Standard errors are corrected for heteroscedasticity and autocorrelation by following Newey and West (1987).

As to portfolio performance, when focusing on the analysis from 2010 to 2015, only the green portfolio displays positive and statistically significant abnormal returns. As to the period from 2016 to 2020, both the green and the polluter portfolios show positive abnormal returns. The alpha of the GMP portfolio is insignificant in both portfolios, indicating no statistically significant differences between the green and the polluter portfolio in any of the subperiods.

5.3. Pricing the Risk Factors

In this section I explore how the GMP factor impacts the cross-section of stock returns. For this purpose, I used a panel regression approach, considering the same four-factor model used in section 5.1. along with the value-weighted GMP factor. Table 6 presents the results:

Table 6: Coefficients of the panel regression - estimation of the GMP risk premium

Predictors	*Estimates*	*p-value*
Mkt-rf	0.842 (39.252)	<0.001***
GMP	-0.090 (-2.357)	0.006***
SMB	-0.249 (-6.291)	<0.001***
HML	-0.668 (-17.476)	<0.001***
MOM	-0.402 (-15.738)	<0.001***
Observations	132	
R^2 / R^2 adjusted	0.605 / 0.601	

This table reports the price of the carbon risk factor based on a panel regression for the average returns of 406 companies from the Euro STOXX 600. The inputs are the monthly risk factor premiums for the following factors: GMP is the Green-Minus-Polluter factor; MKT-rf is the market excess returns; SMB is the Small-Minus-Big factor; HML is the High-Minus-Low factor; MOM is the momentum factor. T-statistics are in parentheses, reported based on standard errors. Note: The asterisks *, ** and *** denote statistical significance at the 10%, 5% and 1% level, respectively.

As one can see in table 6, the R^2 is 60.5%, which means that the model has a strong explanatory power when it comes to explaining excess returns.

The results show that all risk factors are statistically significant. The premium associated to the GMP factor is negative and significant at the 1% level. The negative sign of the GMP factor is consistent with the expectations that polluter firms require a positive risk premium. This is in line with the results of Bolton and Kacperczyk (2021) and Hsu et al. (2022), which document the existence of a carbon risk premium, meaning that investors demand a risk premium to invest in more polluter stocks. Bolton and Kacperczyk (2021, p. 5) point out that "our finding that stock returns are positively related to the level (and changes) of carbon emissions is largely consistent with the view that investors are pricing in a carbon risk premium at the firm level". These results are also consistent with Alessi et al, (2021, p. 8) that stated that "a negative greenium indicates that investors accept lower compensation, ceteris paribus, to hold assets that correlate positively with the greenness and transparency factor".

6. Conclusions

The awareness about climate change is increasing among European and worldwide investors, and a flourishing literature addresses the impact of climate risks in financial markets. The conclusion that climate risk matters when it comes to financial investments is supported by several studies which examine the financial effects of climate risk. Hence, incorporating climate risk into the investment process is gaining importance. In this research I address this issue by forming portfolios of green firms and polluter firms in the European market, based on the carbon emissions of the companies that constitute the Euro Stoxx600 Index. I also form the GMP factor, which is the difference between the returns of green and polluting portfolios. I start by evaluating the performance of green and polluting equally and value-weighted portfolios, as well as the GMP portfolio. The results obtained show that the Carhart model (1997) has high explanatory power when it comes to explaining excess returns for both the green and the polluter portfolios. As to the portfolio performance, both portfolios present positive abnormal returns, and there is no statistically significant differences between the performance of the green and polluter portfolio. In general, both the green and the polluter portfolios (equally and value-weighted) are sensitive to the used risk factors (Market-rf, SMB, HML and MOM), as these factors are statistically significant and contribute to explaining the portfolios' excess returns. Furthermore, the analysis for sub-periods shows no significant differences in the performance these portfolios whatever sub-period considered.

I further analyze whether the GMP factor explains systematic variations in returns and provides evidence of a risk premium associated with carbon risk, using a panel regression approach. The results show that companies from the STOXX 600 are sensitive to the GMP risk factor and that this factor is negative and statistically significant, which means that investors require a positive risk premium to invest in polluter firms. This extra risk factor constructed in this paper can be used as a tool to establish the green sensitivity of a portfolio, by just computing their green beta.

Overall, the evidence of this dissertation indicates that climate risk is an important risk factor when it comes to explaining expected returns. This dissertation contributes to research regarding the integration of carbon risk into the analysis of investment portfolios, concluding that carbon risk should be considered on the equation.

This study has some limitations to account for. Some of them concern the availability of data. The data in this paper was retrieved from Refinitiv Eikon and Refinitiv Datastream, where there is missing data regarding carbon emissions and revenues, leading to the exclusion of some stocks of the Euro STOXX 600. Another possible limitation concerns the factors used when running the econometric regressions. There are some factors that could be included in the analysis, that would probably increase the models' explanatory power and its accuracy, such as RMW (Robust Minus Weak) and CMA (Conservative Minus Aggressive).

In terms of suggestions for future research, a possible improvement could involve constructing the GMP factor in a dynamic way by considering the historical constituents of the Euro STOXX 600 over time. Furthermore, considering the increasing attention to climate risks in recent years, a possible avenue of future research would be to implement a time-varying risk premium model.

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