THE ROLE OF A GREEN FACTOR IN STOCK PRICES.

WHEN FAMA & FRENCH GO GREEN

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ABSTRACT

Concerns about climate change are now widespread, and the risks for financial assets have become more evident. Investors are increasingly aware of the need to incorporate climate-related considerations in their investment decisions. All this has had an impact on market valuations. In this paper, we extend the framework of the factor models that explain the expected return of stock models to include a climate change exposure factor. To do so, we built a portfolio that is long on companies with low carbon emissions, and short on companies with high carbon emissions. We show that this factor is relevant in the market and allows for an approximation of the climate change exposure of firms with poor disclosure of their green performance. Thus, the betas of this factor could be a useful tool for investors that wish to incorporate these aspects in the management of their portfolios and analysts interested in corporate exposure to climate change risks.

Keywords: Climate Change; Carbon footprint; Factor Model; Asset Pricing; Disclosure

JEL Codes: G12; Q54; G24

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1. Introduction

The awareness of the risks associated with climate change in the economic and financial sphere has increased worldwide in recent years, especially since the signing of the Paris Agreement and the 2030 Agenda for Sustainable Development of the United Nations. This has led to a frenzied agenda by governments (González, 2021a) and central banks (González, 2021b) of regulatory changes in the financial markets to allow them to funnel the funding needed to transform the economy towards one less dependent on fossil fuels (i.e., a climate-neutral economy). At the same time, financial markets have developed even quicker than regulation, with the appearance of new green financing instruments and standards, such as green bonds, syndicated loans and project finance (González and Núñez, 2021).

In line with these developments, ESG information has become financially material to investment performance (Amel-Zadeh and Serafeim, 2018). Ilhan et al (2020) find that a large majority of investors believes that climate risk reporting is as important, or even more, than reporting on traditional financial risks and, at the same time, consider that improvement in disclosure is needed and should be standardized and mandatory. Lack of standards and data availability makes more difficult to design an investment strategy that takes into account the risks of Climate Change and the opportunities of the economic transformation required to fight it. For instance, Gorgen et al. (2020), while screening for climate related variables to produce their Brown Green Scores, have to reduce their initial 26664 companies listed into just 1657 once you discard those without disclosure.

The aim of this paper is to use the market efficiency to derive an indirect measure of the shade of green of a financial asset (or portfolio) even in the absence of firm disclosure. Any advance in this line of research is of special relevance for accelerating the provision of tools for asset managers for the incorporation of climate change to their portfolio management, in particular those that allow to have proxies for those companies that don't make disclosure yet. To do so, we take advantage of investors' attention to green issues, and design a green factor that can be used to obtain a proxy of the greening of those companies that don't disclose their carbon footprint.

Gimeno and Sols (2020) showed how investors might sacrifice return in order to get (nonmonetary) utility in terms of sustainability. Pástor et al. (2021a) formalized this logic in a theoretical model that classifies firms in "green" and "brown", showing how investors get utility from green assets, and disutility (needed to be compensated in terms of return) from brown assets. In these framework, drifts in relative utility of both type of assets might produce changes in the relative demand and prices of both type of assets. The theoretical model of Pedersen et al. (2021) also predicts lower expected returns for ESG assets in equilibrium and positive returns if risks are not fully priced.

Empirical analyses have also show that financial assets reflect the climate change related risks into their prices, although with some divergences in their results. For instance, Engle et al. (2020), built an index of climate change news, and fond that stocks react to that index. Chava (2014) finds that firms with climate change exposure have a significantly higher cost of equity and debt capital. Matsumura et al. (2014), find a positive market reaction to carbon emissions disclosure (and a negative one for the volume of emissions); and Ziegler et al. (2011) show a positive return by investing in disclosing companies and selling non-disclosing ones. By contrast, Bolton and Kacperczyk (2021) find that returns are higher for high emission companies; while Alessi et al. (2021) find better performance for non-disclosing firms than for low emissors. Oestreich and Tsiakas (2015) found that those companies receiving carbon emissions allowances outperformed those that did not receive it in Germany. All these divergences might be explained by the differences in sample periods and companies. For instance, Choi et al. (2020) found that low carbon emission companies outperform high carbon emissors when temperatures are abnormally high. Monasterolo and De Angelis (2020) found that systemic risk is reduced and there is an increase in the weight on optimal portfolio for low carbon emissions companies after the Paris Agreement, while Faccini et al. (2021) find that markets react when there are expectations of imminent US government interventions to fight climate change. The empirical evidence that stock prices are reacting to climate related factors, implies that we can turn it around and use these movements as indications of climate risk exposures, in line with the approach of Bansal et al. (2021), who estimate the sensibility of stock returns to changes in temperatures (a proxy to climate change physical risk).

Therefore, in our case, we extend the framework on the factors explaining the expected return of stocks to add a climate change (transition risk) exposure factor. The use of asset pricing models to identify the main factors driving prices or expected returns of financial assets is a well-established line of research. The extensive research of Fama and French (1992; 1993; 1995; 1996; 1998) expanded the initial classical CAPM model of Sharpe (1964), Lintner (1965) and Black (1972) from a perspective of the factor analysis/principal components framework to include additional factors influencing the cross-sectional variation of stock returns. In the case of Fama and French (1993), they built a three factor model with Market Size and the Book to Market ratio of the companies as new factors. Later, Carhart (1997) added a fourth factor to the Fama and French (1993) three factor model called Momentum. Many papers have extended this approach to other potential factors, such as Petkova and Zhang (2005) for value and growth, Gompers et al. (2003) for corporate governance, or Hong and Kacperczyk (2009) for company compliance with social norms.

In line with this stream of literature, we construct a green factor based on companies' carbon footprints. However, we depart from them in several ways, especially in the way we identify the companies that belongs to each portfolio. Gorgen et al. (2020), built the portfolios using a set of 300 variables to create brown-green scores. This method produces a very complete picture of environmental situation of firms, but reduce the possibility of tracking the feasibility of using the factor as intended in this paper to proxy the carbon emissions of non-disclosing firms. Alessi et al. (2021), use companies with low carbon emissions for the long portfolio, but use companies that do not disclose their carbon footprint for the short portfolio, using the argument that they do not disclose because they have a high footprint. Nevertheless, we consider in this paper that there might be other reasons for not disclosing: they are companies of relative small size and the cost of disclosure is higher for them, and the investors pressure is lower given that reporting is not mandatory. The analysis of Luo et al. (2012) obtains that larger firms are willing to disclose carbon information voluntary even in the case of voluntary frameworks because they are aware of their social responsibility. Moreover, investor pressure is also lower for companies whose activities are not specially carbon intense. For instance, Kouloukoui et al. (2018) find that the level of disclosure regarding climate risks depends on the sector of activity of a company, being more likely to disclose environmental information in the cases of companies from economic activities potentially polluting. Luo et al (2012) show that those companies that do not disclose are more likely to be in the non-carbon intensive sectors. These previous findings trigger us to further depart from Alessi et al. (2021), by ensuring that portfolios are balanced in terms of industry and size, to avoid that the factor is mixed with considerations not related to climate. All these departures allow us to use the stock sensitivity to the climate factor as a proxy of climate risk exposure.

In the paper, we show that this green factor provides relevant information on the stock price movements that cannot be explained with other stock factors proposed in the literature (i.e., it is orthogonal to them). In fact, the explanatory power is superior to some popular factors such as the momentum, the investment policies, or the consistency of profits, and perfectly in line with the original factors of the Fama and French (1993) three factor model (i.e., Market, Size and Book to Market). More importantly for the purpose of the paper, we show that this factor has a high correlation with the carbon footprint. In fact, the way we have built it, allows us to use it for companies not included in the portfolios, and could be used as a good proxy to cover data gaps, something especially relevant in an environment with many firms with poor disclosure and erratic ESG ratings. The green factor is constructed for the US and European stock markets for the period 2002-2020. The transition to a low carbon economy has different paces of development in both geographical areas, as well as regulation and the way the investors incorporate such aspects so it is important to be able to compare.

2. The Green Exposure as a differentiated Market Factor

In this paper, we extend the work of Fama and French (1993, 2015) and Carhart (1997), to propose a model where the excess return of individual stocks is driven by the market factor, the size (SMB) and growth-value (HML) from Fama and French (1993) 3 factors model, the momentum factor (WML) from Carhart (1997), the profitability (RMW) and investment opportunities (CMA) from Fama and French (2015) 5 factors model, and a final GMP factor that we add (see equation 1). This GMP compares the performance of those companies with lower emissions to that of those ones with higher emissions (hence the green minus polluter, GMP, name).

$$R_{it} - Rf_t = \alpha + \beta(E[Rm_t] - Rf_t) + \gamma_{WML}(W_{MOM,t} - L_{MOM,t}) +$$

$$+\gamma_{SMB}(S_{MS,t} - B_{MS,t}) + \gamma_{HML}\left(H_{\frac{B}{M},t} - L_{\frac{B}{M},t}\right) +$$

$$+\gamma_{RMW}(R_{PROF,t} - W_{PROF,t}) + \gamma_{CMA}(C_{INV,t} - A_{INV,t}) +$$

$$+\gamma_{GMP}(G_{CO2,t} - P_{CO2,t}) + e_{it}. \quad (1)$$

In order to construct the GMP factor, we need a measure of the carbon emissions of each company. We choose the ratio on the tons of CO_2 equivalent emissions disclosed (scope 1) per million of US dollars in income. We use scope 1 emissions because they are the most frequently disclosed ones, and we normalize by income, following TFCD recommendations, in order to control for the company size (in line with the precautions in other models to get factors orthogonal to the size). There are certain characteristics regarding the carbon emissions that are relevant for the portfolio we are planning to build. First, these emissions are reported only annually, and although they have a tendency to decline over time for all companies, the ranking of companies does not vary significantly from one year to other. For this reason, there is no need for constantly recalibrating the portfolios. Second, not all companies report their carbon emissions, and not from the same starting moment, since this is something that has been increasingly appearing in their non-financial reports. For this reason, we have opted to use the last available data of carbon emissions of each company to build the portfolio.

We have used, as a starting point, the companies that are part of the S&P500 and the Eurostoxx600. From this 1100 companies, we have excluded, in a first step, the financial ones, since they are eminently companies with a very low carbon footprint, and if we would have included them we have a serious risk of mixing the green factor with a financial factor in the same portfolio. This reduces our sample to 864 companies (408 and 456 for US and Europe, respectively).

From these companies, we track the last available CO_2 emissions, that is reported for just 468 companies (142 and 326 in US and Europe respectively). As we have previously mentioned, disclosure of carbon emissions is not mandatory, and companies might decide to opt-out of reporting for several reasons. The differences between Europe and US are striking in this case. Main reasons are in different investors pressure on disclosure, as well as the more developed carbon credit market in Europe, that require companies in certain activities to disclose their carbon footprint, in order to cover it with carbon credits, making more difficult to avoid non-disclosure. There are other factors that are common for both economic areas. For instance, companies might want to save the costs of estimating such emissions, what would reduce the likelihood of disclosure on small companies. Investors might not exert pressure for disclosure for companies that are not in sector especially green or with high carbon footprint. Finally, companies might not want to highlight the potential high level of emissions they produce (as proposed by Alessi et al. 2021). We will show how the sensitivity of each company to the GMP factor might help to approximate the carbon footprint of these non-disclosing companies.

With the available data we sort the companies by their carbon footprint and pick the 50(60) with the lowest footprint in US(Europe) and the 50(60) with the highest footprint in US(Europe). Although the proportion of company with available data is not the same in both areas, the level of emissions for both areas are not that different: 35 tons per million in US and 7.5 in Europe for the green portfolios, and 170 tons for US and 198 tons in Europe for the polluter portfolios. This allow us to get portfolios of green and polluter companies in each region (see Fig. 1).

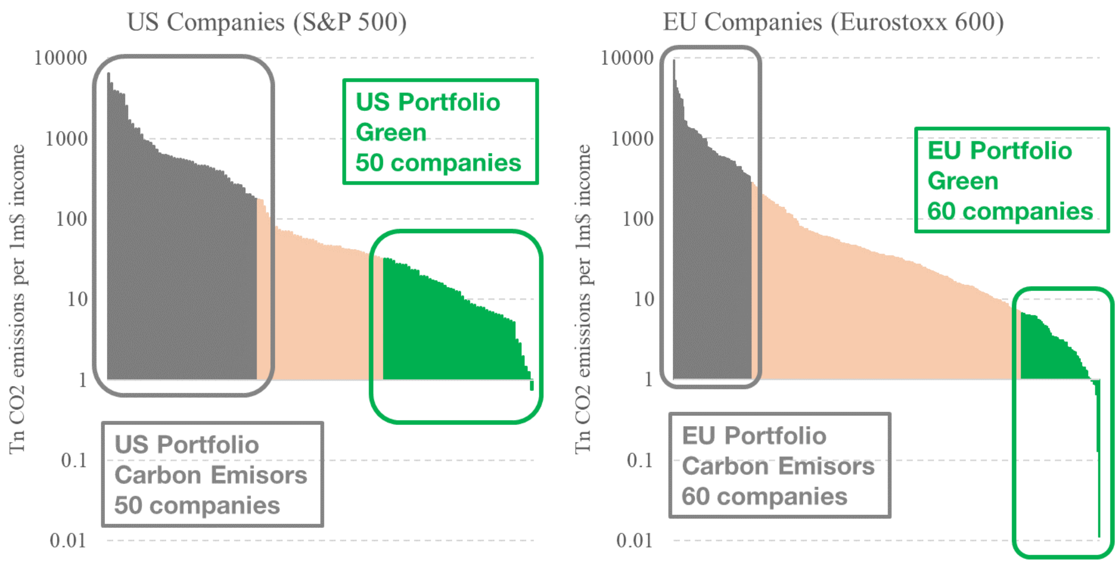

Fig. 1: Carbon footprint (tons of CO_2 equivalent emissions per million of income) of S&P500 and Eurostoxx600 companies, highlighting the ones picked for the green portfolios (green) and the polluter portfolio (grey).

Once we have the companies classified in green and polluters, for each region, we build equally weighted portfolios. Fig. 2 (orange lines) shows the cumulated return for each of the four portfolios (i.e., green US, polluter US, green EU, polluter EU). The performance of the green portfolios is different from the performance of the polluters. By contrast, there are remarkable similarities in the performance of green portfolios both in US and Europe, as well as between the polluter ones in the same regions. This is a clear sign that we are capturing a genuine factor.

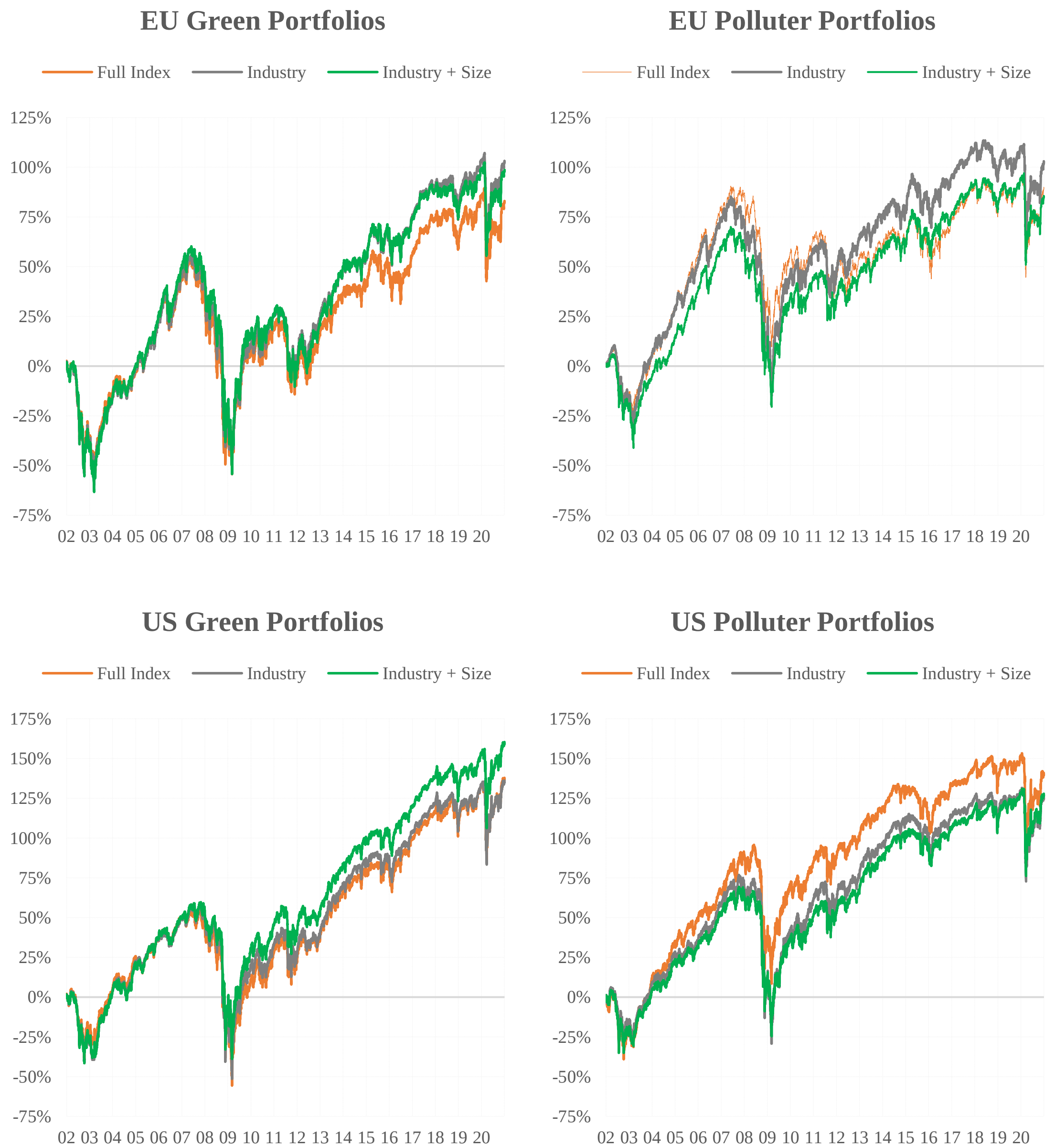

Fig. 2: Cumulated return of the equally weighted portfolios of the greener companies (left) and polluter companies (right) in US (bottom) and Europe (top). Orange lines represent the portfolios using the full sample of companies. Grey lines represent portfolios balanced by industries. Green lines represent portfolios balanced by both industries and company sizes.

Finally, the GMP is built as a compound portfolio that is long on the green portfolio and short on the portfolio of polluter companies (hence the green minus polluter, GMP, name). Fig. 3 shows the cumulated returns of these portfolios across the whole sample period from 2002-2021. There is a striking similitude in the behavior of the portfolios on both areas, confirming that we are measuring a similar factor in both cases. There is also a clear change in the sign of the evolution, with negative returns predominant in the first decade of the 21st century, and positive returns in the second decade. At the same time, we can see that the moment in time when this issues gain in relevance is different between US and Europe as we will see in the next section. This evolution goes in line with the predictions from the theoretical model of Pástor et al. (2021), since one would expect that green assets would underperform non-green assets in general terms (due to the need of monetary compensation of the utility loss in terms of sustainability of the non-green assets), while an increasing climate change awareness in the last decade whole drift investors demand for green assets, producing the later rise in the return of the factor. This outcome also matches the evidence in Ilhan et al. (2021) that investors require a compensation for the transition risk, that was reduced during the Trump Presidency in the US.

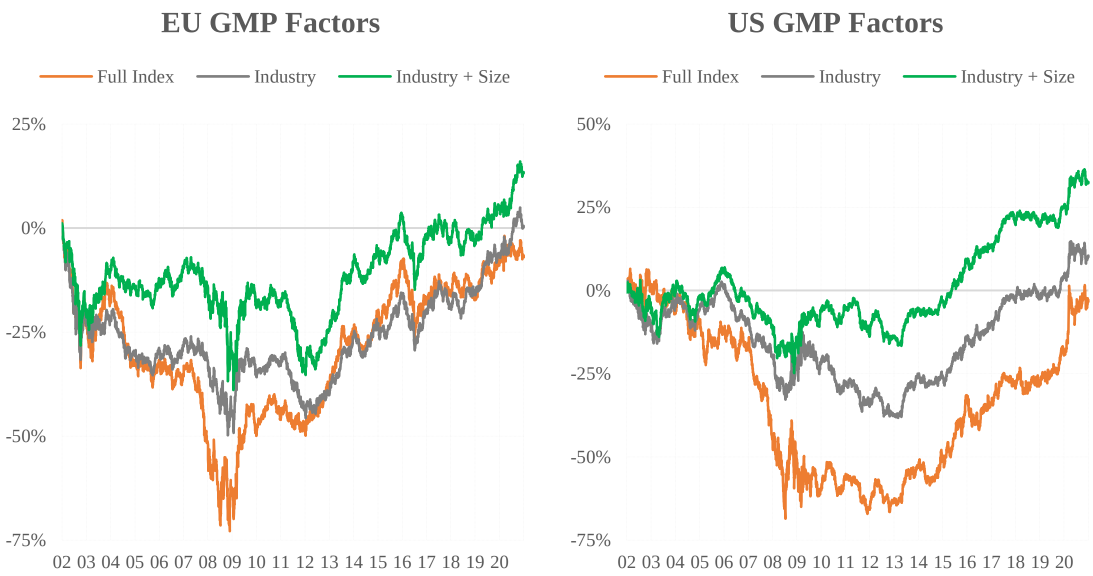

Fig. 3: Cumulated return of the GMP factor, built as a portfolio going long for green companies and short for polluter companies in Europe (left) and US (right). Orange lines represent the portfolios using the full sample of companies. Grey lines represent portfolios balanced by industries. Green lines represent portfolios balanced by both industries and company sizes.

Once we have this GMP factor, we evaluate its relevance in comparison with the ones that are common in the literature, such as the SMB, HML, WML, RMW, or the CMA. In order to do so, we need to ensure that GMP is giving a signal that is not already in the other factors. As a corroboration of the low correlation of GMP with the other factors, we have run a regression of the log return of GMP on the other factors (see Table 1, columns 1 and 4). The coefficients of determination (i.e., R^2) are just 15% for US and 26% for Europe, confirming that GMP is capturing a market movement that was not previously observed by the previous factors.

Table 1. Regression of the GMP factors on the other market factors

	(1) US GMP Full Index		(2) US GMP Industry		(3) US GMP Industry & Size		(4) EU GMP Full Index		(5) EU GMP Industry		(6) EU GMP Industry & Size	
MKT	0.030	***	0.032	***	0.062	***	0.068	***	0.057	***	0.126	***
	(.009)		(.006)		(.008)		(.010)		(.009)		(0.009)	
SMB	-0.078	***	-0.175	***	-0.003		0.030		-0.040	**	0.059	***
	(.017)		(.012)		(.016)		(.020)		(.017)		(0.018)	
HML	0.106	***	0.043	***	-0.011		-0.240	***	-0.130	***	0.029	
	(.018)		(.013)		(.017)		(.021)		(.017)		(0.018)	
RMW	-0.545	***	-0.374	***	-0.304	***	-0.776	***	-0.622	***	-0.647	***
	(.025)		(.018)		(.023)		(.030)		(.025)		(0.026)	
CMA	-0.259	***	-0.146	***	-0.081	**	-0.302	***	-0.308	***	-0.465	***
	(.032)		(.023)		(.030)		(.029)		(.024)		(0.025)	
WML	-0.043	***	0.029	**	0.005		-0.121	***	-0.056	***	-0.078	***
	(.012)		(.009)		(.011)		(.011)		(.009)		(0.010)	
Cons.	0.000		0.000		0.000		0.000	**	0.000	**	0.000	***
	(.000)		(.000)		(.000)		(.000)		(.000)		(0.000)	
# obs.	4805		4805		4805		4957		4957		4957	
R2	0.152		0.130		0.066		0.226		0.234		0.340	
F	143.87	***	119.74	***	56.56	***	240.34	***	251.71	***	424.30	***

Note: Regression of the log return of the GMP (green minus polluter) factor on the log returns of the other market factors (i.e., MKT (market excess return); the Fama & French (1993) SMB (small minus big) and HML (high minus low); the Carhart (1997) WML (winners minus losers); the Fama and French (2015) RMW (robust minus weak) and the CMA (conservative minus aggressive). Left columns are the regressions for US and right columns for Europe. In Columns 1 and 4, regressions are performed on the initial (full index) GMP factor, where two portfolios are built using the 10% with less(more) GHG emissions; Columns 2 and 5 represent the regressions on the alternative GMP factors where the portfolios are built using the 10% with less(more) GHG emissions in each industry; Columns 3 and 6 are the regressions for the GMP factors built using the 10% with less(more) GHG emissions in each industry, with half small and half big companies in each industry. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance levels.

However, in this initial analysis, one might argue that the GMP factor is capturing a difference in the industry composition of the green companies and the polluter ones (see Table 2), and that this difference is not related to the GHG emissions but on other features of these industries that makes them evolve in opposite directions.

Table 2. Sector breakdown of green and non-green portfolios.

	US		Europe	
	Green	Non-green	Green	Non-green
Basic Materials	0	9	2	20
Communications	7	0	14	0
Consumer, Cyclical	6	5	12	7
Consumer, Non-cyclical	19	2	15	2
Energy	1	14	2	7
Industrial	8	9	8	5
Technology	9	0	7	1
Utilities	0	11	0	18

In order to control for this possibility, we have created alternative portfolios, ensuring that there is the same industry composition in each portfolio as the one you observe in the general index (this allows us to include again the financial sector). Thus, for each industry, we have chosen the 10% with the lowest(highest) GHG emissions for the green(polluter) portfolios. One might consider from an investors perspective, that the original GMP factor for the full index represents a *best-in-universe* investment strategy, while the industry balanced GMP factor represents a *best-in-class* investment strategy. The evolution of those portfolios presented in the grey lines of Fig. 1 and 2. There are small differences from the original portfolios, but, in general, keep the same upward trend and cumulated return of the similar magnitude. Regressions of the daily log returns of the alternative GMP on the other standard factors, show a level of orthogonality with them that is even higher than in the original GMP. In fact, the R^2 are just of 13% for US and 24% for EU, compared with 15% and 26% respectively for the original GMP factors (Table 2, right columns). Thus confirm that the GMP is a factor that covers movement that are different from standard factors in the literature.

In a final step, we have considered that there might be also differences in the size of companies in the considered portfolios. In order to ensure that there are no size distortions, we have built a new portfolio where, for each industry, we have divided companies by their market capitalization in below or above the median, and ensure that half the companies included in each industry-portfolio are small and half are big. This has implied that we have to change 6 (8) companies in the green portfolios in US (Europe), and 9 (10) companies in the polluter portfolios in US (Europe). The new portfolios are represented by green lines in Fig. 2 and 3. The ortogonality of the US GMP has dramatically increase with this (R^2 is just 6%) but increase for Europe (R^2 is 34%).

3. Financial Relevance of the Green Factor

In order to evaluate if the proposed GMP factor has a real relevance compared with other more traditional factors already used in the literature, we have to check if this GMP factor has a capacity to explain the evolution of the stock prices. We start from the daily (log) return of each of the companies in the S&P500 and Eurostoxx600 (wide) indexes. We subtract the risk free rate for each area from the returns to obtain the excess return for each company. This is the variable we explain using regression analysis.

As explanatory variables, we use the MKT factor from the CAPM model of Sharpe (1964), Lintner (1965) and Black (1972), the SMB and HML factors from Fama and French (1993), the WML factor from Carhart (1997), the RMW and CMA from Fama and French (2015) as well as the GMP computed with industry and size portfolio balance for each economic area (i.e., US and Europe) and industry effects. We start the analysis looking to sort the relevance of each factor to explain the excess return of each company. To assess the relevance, when we are looking at 1100 different models (one for each company), we use the Shapley decomposition of the coefficients of determination, R^2, (Huettner and Sunder, 2012) to obtain the contribution of each explanatory variable to the overall R^2 of each regression. Fig. 4 shows the median value for each factor (excluding the MKT factor that represents around 42% in US and 33% in Europe of the overall coefficient of determination). As can be seen, the magnitude of the GMP contribution is similar to that of other traditional (and popular) factors, and in the case of Europe, only shadowed by the SMB factor.

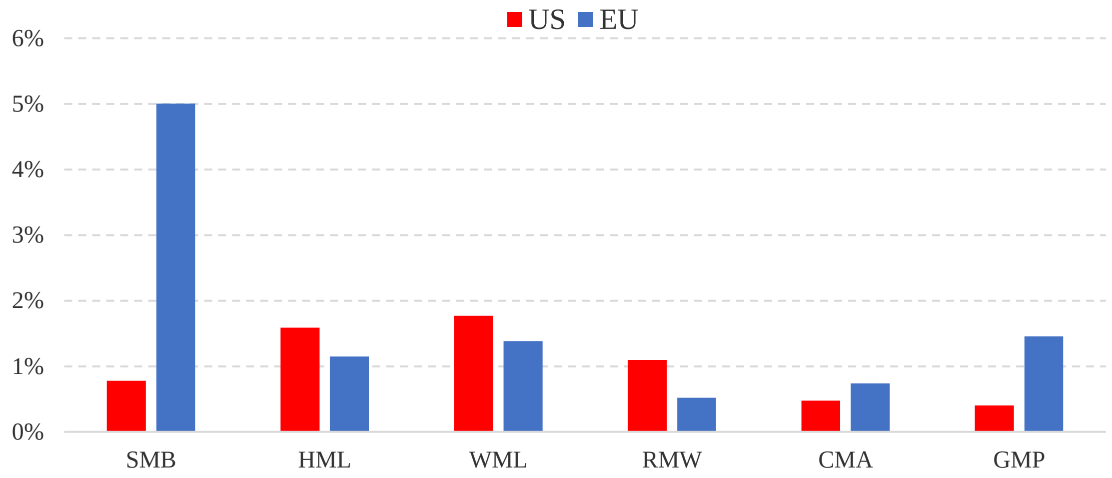

Fig. 4: Median values of the Shapley decomposition of R^2 for each market factor on the daily log excess return for each company in the US (S&P500, red) and Europe (Eurostoxx600, blue).

Going to the individual regressions, Fig. 5 shows the estimated value of the coefficient of the GMP factor for each company in the regressions with all the factors. As we will expect by construction of the factor, we have companies where GMP has a positive impact on the excess return and companies with a negative impact. Comparing both economic areas, we find higher positive sensitivities in Europe and higher negative sensitivities in the US.

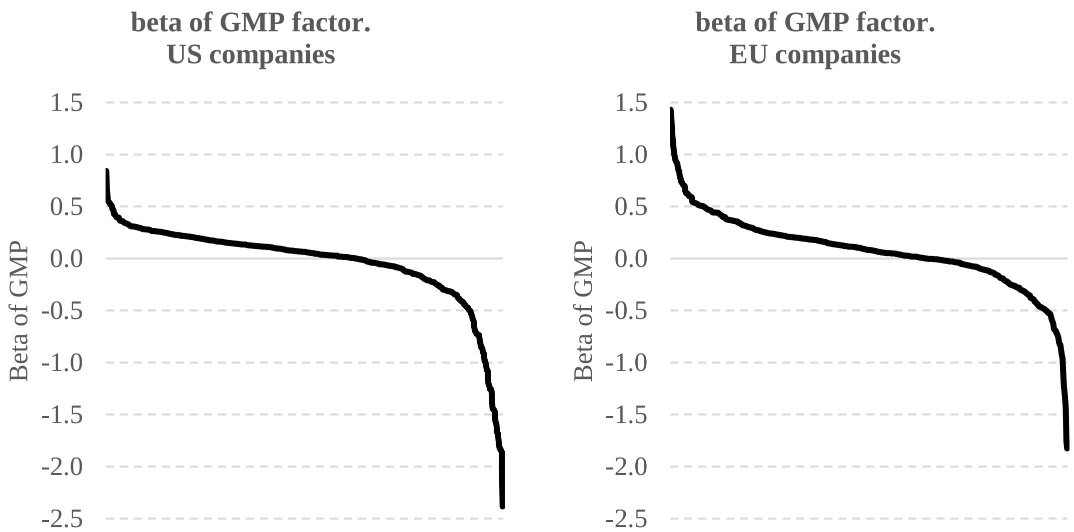

Fig. 5: Values of the GMP coefficient on the regression of the excess (log) return of each company in S&P500 and Euronext600 on all the market factors (MKT, SMB, HML, WML, RMW, CMA, as well as GMP, and industry effects).

The breakdown of the average coefficients between the green, polluters, the excluded companies and the ones without data (Fig. 6, left panel), shows that the results are consistent between both economic areas, with coefficients for the green portfolios higher in Europe than in the US, while the portfolio for polluters shows more negative values in US than in Europe. In the case of the companies with no available GHG emissions, the coefficients are not different from the companies non included in the portfolio of polluters or green companies. The breakdown by sector shows too the same hierarchy for both economic areas, with the financial sector, communications and technology with the greener companies, while utilities, energy and basic materials with the polluter ones (Fig. 6, right panel).

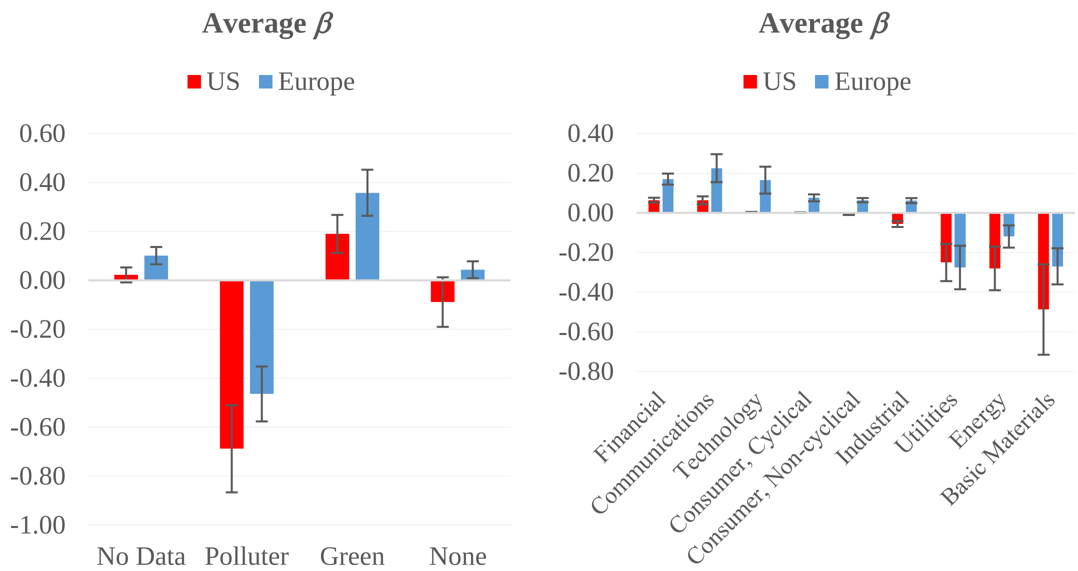

Fig. 6: Breakdown of the average values of the GMP coefficient on the regression of the excess (log) return of each company in S&P500 and Eurostoxx600 on all the market factors (MKT, SMB, HML, WML, RMW, CMA, as well as GMP and industry effects). Left panel, decomposition in the different portfolios used for the construction of GMP factor. On the right panel, by the industry

Finally, regarding the significance of the GMP in those regressions (Fig. 7), 55.6% of US companies and 48.3% of European companies show a GMP coefficient that is statistically significant at the 1% level, far exceeding the 20% of companies that were used to build the portfolios in the GMP factor. The proportions of significant cases rise to 65% and 55.8% for US and Europe respectively at the 5% significance level, and to 70,6% and 62.2% for US and Europe at the 10% significance level.

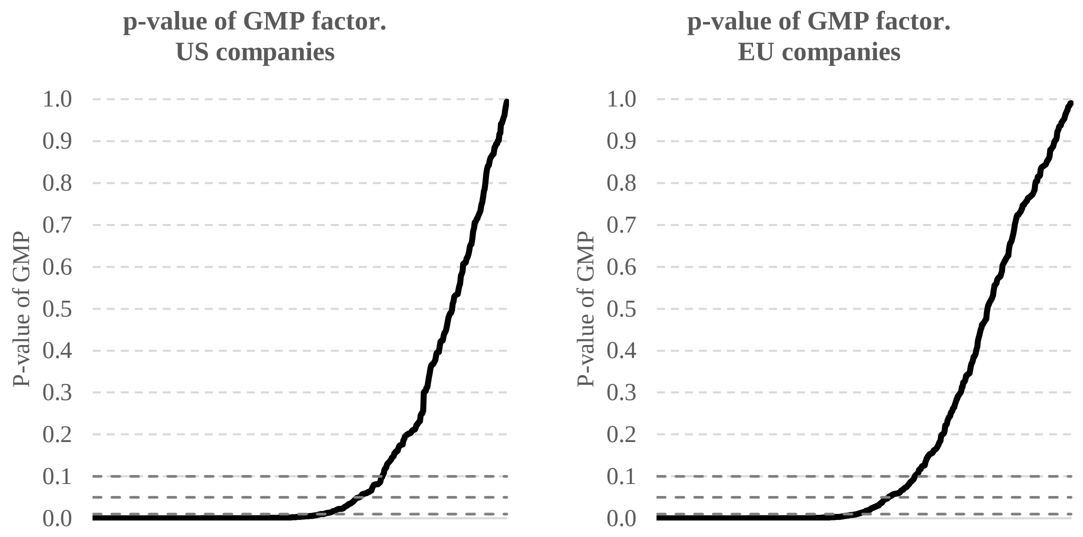

Fig. 7: *p*-values of the GMP coefficient on the regression of the excess (log) return of each company in S&P500 and Euronext600 on all the market factors (MKT, SMB, HML, WML, RMW, CMA, as well as GMP, and industry factors).

3.1. The change in time of the investors' attention to climate-change issues.

The fight against climate change (and to avoid its worst consequences) implies the development of the adequate framework allowing financial flows to reach sustainable activities. Investors' attention on climate-change issues has evolved over time. Ardia et al. (2020) construct a Media Climate Change Concerns Index and find that when concerns about climate change increase unexpectedly, green firms' stock prices increase, while brown firms' decrease. Similar results obtain Pastor et al. (2021b) that green stocks typically outperform brown when climate concerns increase. The Climate Change News Index of Engle et al. (2020) shows spikes during some remarkable climate events, such as the adoption of global climate treaties or important global conferences. In Europe, Ramelli et al. (2021a) find that the Global Climate Strike on March 15, 2019, caused a decrease in the stock prices of carbon-intensive firms, effect that can be attributed to the increased public attention to climate activism.

In addition, there may be geographical differences between US and Europe in the way and evolution in the incorporation of these aspects in the investment process. Gibson et al. (2021) find that PRI signatories exhibit better ESG portfolio-level scores but this holds only outside of the US. In the case of US-domiciled signatories, the authors do not find better scores, even for those that report full ESG incorporation and those that report no ESG incorporation actually have, on average, worse scores than non-PRI investors.

According to the authors, the disconnection of US appears to be driven by a more business oriented approach to ESG, as opposed to ESG investing that is intrinsically motivated by social norms more prevalent in other parts of the world.

Differences in the way ESG issues are incorporated into investment management, the evolution of public initiatives and regulations also play a key role. The policy response against climate change have had several phases and different evolution in US and Europe. Indeed, we have performed a separate analysis for US and Europe because the pace of regulation is different in both areas. In fact, the significance of the green factor has changed in time, and in line with the public activity, as can be seen in Fig. 8 (i.e., the evolution of R^2 from 2008 to 2020, through a one-year rolling window), and it is very different between economic areas until 2020.

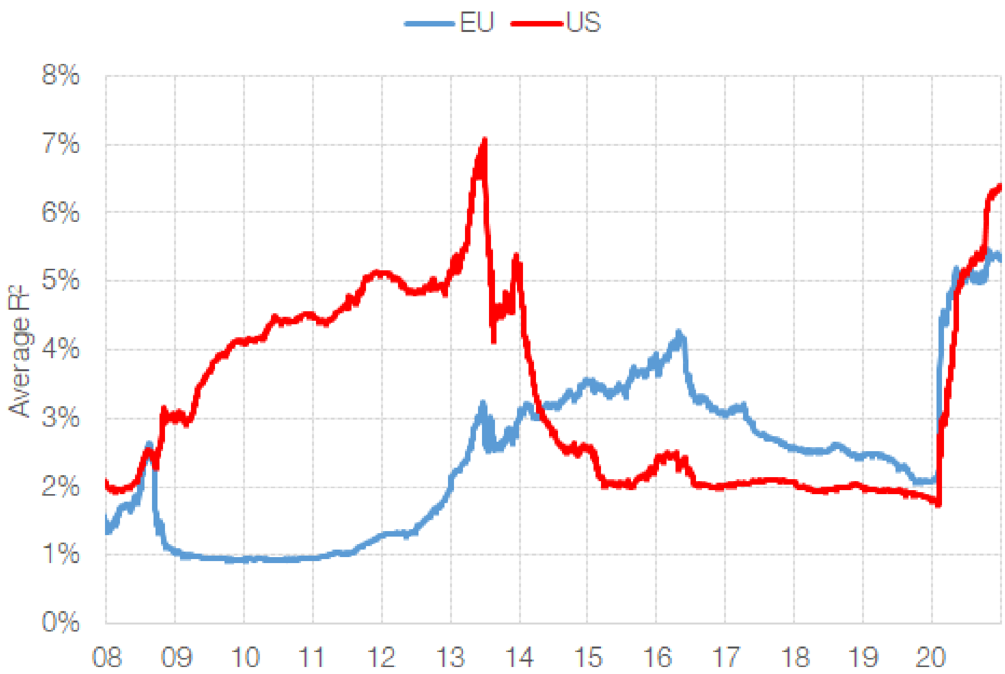

Fig. 8. Average R^2 in a rolling window for US and Europe.

The performance of the GMP portfolio is in line with the prediction of the theoretical model of Pástor et al. (2021a), where increasing attention to climate change produce an outperformance of green assets, while a reduction of the attention would produce an underperformance of the same assets.

In the case of US, we can see two stages: first, until mid-2013; and the second afterwards, both marked by the political developments. The Obama administration put in place a number of programs that attempted to address the impact of climate change. Many of the investments under the American Recovery and Reinvestment Act of 2009 were focused in clean energy and President Obama set a number of new regulations and plans in order to fight climate change. For example, in 2009 new regulations for automobile emissions were imposed and a Clean Power Plan was developed between 2013 and 2015. However, during Obama's second term the lack of a majority in the House of Representatives, and, in the Senate after November 2014, implied that it was not possible to pass new climate change legislations through Congress. Since 2017, under Trump's administration, the advances were blocked and the country withdrew from the Paris agreement although the US rejoined in February 2021 under the Biden's Presidency that announced new targets regarding climate policy.

According to Faccini et al. (2021), US investors price only specific aspects of climate risk in particular regarding transitions risks steaming from regulations when they come to the political debate and specially after 2012. Ilhan et al. (2021) obtain that the cost of downward option protection significantly decreased at highly carbon-intense firms after President Trump's election in 2016, relative to other firms, when it is magnified when public attention to climate change spikes. And Ramelli et al. (2021b) find that investors reacted to the election of Donald Trump in 2016 by rewarding carbon-intensive firms, they are the most exposed to the costs of climate regulation. These authors obtain at the same time that investors also rewarded companies demonstrating more responsible climate strategies because they expected the rollback in climate regulation to be transitory and after the 2020 US election, the value of climate-responsible firms soared in anticipation of the changes in the climate agenda with the change of President. Seltzer et al. (2021) find that Paris Agreement had negative consequences for US firms in top polluting industries or with poor environmental performance being these negative consequences stronger in states that enforce regulation more strictly.

On the other hand, according to Fig. 8, it seems that, until 2014 in Europe, the climate issues where out of the markets. In that year, the IPCC published its fifth assessment report where was stated that human influence on the climate system is clear and growing (IPCC, 2014) that implied a relevant point in time, joint with the sign of the Paris Agreement in 2015, which lead to an increase in the relevance of this topic and the starting point of various institutional initiatives. The European Union formally ratified the Paris agreement in 2016, and the European Commission started to work on sustainable finance creating the High Level Expert Group which work was the base of the Action Plan on Sustainable Finance started in 2018. During 2019 and 2020, this action plan has materialized in ten actions and several regulations, such as an environmental taxonomy. At the end of 2019, the European Commission announced the European Green Deal that comprises a broad package of measures with the aim to become Europe the world's first climate-neutral continent. The latter comprises a broad package of regulation to fight against climate change with the objective to contribute to the mobilization of financial resources to sustainable activities. Moreover, the recovery plan called Next Generation EU has an important compromise with a green and digital recovery.

At the end of 2019 with the organization of UN Climate Change Conference COP25 and in 2020 with the pandemic, the environmental and social issues have gained prominence in the economic and financial areas. There are several international initiatives and climate commitments by banks and asset managers to achieve the net zero objective in their portfolios in 2050 that have been announced under the COP26 and the number of European governments committing to environmental objectives have increased remarkable and the relevance of the topic in the financial markets has rocketed.

4. Information Content of the Green Factor

The sensitivity of each company to the GMP factor (the GMP beta) is a tool that can be used as an index of the green nature of the firm, in line with the use of the corporate governance index of Gompers et al. (2003). In this sense, we expect that this beta will be aligned with the carbon footprints. To test this hypothesis, we regress the reported (log) carbon footprint of each company on the market betas obtained in section 4 (see Table 3). As expected, the higher the beta of the GMP factor (the greener the beta), the lower the carbon footprint. The magnitude of the coefficient is higher when we use GMP factors that controls for industry, or for industry and company size, as a sign that the factor is able to isolate the green concerns of market investors. Although other market factors are significant in one or another regression, GMP is the only one that is consistently significant for all of them. It is also worthwhile to highlight that the models explain between 62% and 77% of the differences in carbon footprints.

One might argue that the previous result is consequence of including in the sample companies that have been used for the construction of the GMP factors, and would not be valid for extrapolate the carbon emission for other companies. To counter this statement, we have run again the analysis, but excluding those firms that are part of either the green or the polluter portfolios. The results are showed in Table 4. We would expect that losing the most extreme values in the sample, the efficiency of the regression would be resented. In spite of this, the GMP factor is still the only relevant factor explaining the carbon footprint of those companies, and the differences in carbon footprints explained by the models reach the 86% for US and 76% for Europe in the case of the factor that controls for industry and size.

Table 3. Regression analysis of the Carbon Footprints

	(7) US Full Index log Carbon Emissions		(8) US Industry log Carbon Emissions		(9) US Industry & Size log Carbon Emissions		(10) EU Full Index log Carbon Emissions		(11) EU Industry log Carbon Emissions		(12) EU Industry & Size log Carbon Emissions	
GMP	-1.489	***	-2.349	***	-4.315	***	-2.843	***	-3.130	***	-3.022	***
	(.206)		(.168)		(.370)		(.248)		(.207)		(.224)	
MKT	-3.235	***	-1.809	***	-1.911	***	0.397		0.361		1.053	***
	(.785)		(.637)		(.648)		(.424)		(.378)		(.401)	
HML	0.185		0.074		0.128		-0.540	***	-0.630	***	-0.437	***
	(.249)		(.209)		(.197)		(.195)		(.162)		(.165)	
SMB	1.003	**	-0.427		0.646	*	0.298		-0.045		-0.252	
	(.436)		(.357)		(.372)		(.205)		(.168)		(.176)	
RMW	-0.014		-0.470	*	-0.409	*	0.506	***	0.316	***	0.381	***
	(.304)		(.240)		(.242)		(.137)		(.116)		(.120)	
CMA	0.204		0.404		0.426		0.244		-0.300		-0.665	***
	(.279)		(.262)		(.271)		(.228)		(.197)		(.222)	
WML	-2.985	***	-1.271		-1.654	**	-1.193	**	-1.181	**	-1.031	*
	(.873)		(.823)		(.755)		(.591)		(.535)		(.537)	
Industry Effects	Yes		Yes		Yes		Yes		Yes		Yes	
# obs.	173		173		173		363		363		363	
R2	0.646		0.775		0.767		0.617		0.725		0.696	
F	24.15	***	41.07	***	43.70	***	31.94	***	45.36	***	41.84	***

Note: Carbon Footprint is measured as the emissions of CO2 tons equivalent per million of income. The explanatory variables are the beta of the excess return of each company to the market factors (MKT, SMB, HML, WML, RMW, CMA, as well as GMP, and industry factors). Left columns are the regressions for US and right columns for Europe. In Columns 7 and 10, regressions use the initial (full index) GMP factor, where two portfolios are built using the 10% with less(more) GHG emissions; In columns 8 and 11, regressions use GMP factors where the portfolios are built using the 10% with less(more) GHG emissions in each industry; Columns 9 and 12 are the regressions using the GMP factors built using the 10% with less(more) GHG emissions in each industry, with half small and half big companies in each industry. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance levels.

Table 4. Regression analysis of the Carbon Footprints. Out of sample.

	(13) US Full Index log Carbon Emissions		(14) US Industry log Carbon Emissions		(15) US Industry & Size log Carbon Emissions		(16) EU Full Index log Carbon Emissions		(17) EU Industry log Carbon Emissions		(18) EU Industry & Size log Carbon Emissions	
GMP	-0.768		-1.616	***	-3.091	***	-1.586	***	-0.939	***	-0.863	***
	(.481)		(.519)		(.855)		(.390)		(.232)		(.259)	
MKT	-2.783	**	-2.691	***	-2.667	***	0.219		-0.145		0.106	
	(1.200)		(.835)		(.801)		(.417)		(.334)		(.356)	
HML	0.076		-0.050		-0.070		-0.464	**	-0.023		0.064	
	(.458)		(.173)		(.253)		(.221)		(.138)		(.144)	
SMB	1.842	**	-0.536		0.472		0.039		0.020		-0.069	
	(.773)		(.387)		(.530)		(.234)		(.140)		(.149)	
RMW	-0.231		-0.112		0.267		0.547	***	0.231	**	0.222	*
	(.788)		(.324)		(.349)		(.160)		(.105)		(.115)	
CMA	0.753		-0.322		-0.307		0.197		-0.068		-0.342	*
	(.475)		(.262)		(.334)		(.284)		(.168)		(.195)	
WML	-2.624	**	-2.524	**	-2.146	**	-1.185	*	-0.322		-0.386	
	(1.188)		(1.073)		(.932)		(.642)		(.420)		(.451)	
Industry Effects	Yes		Yes		Yes		Yes		Yes		Yes	
# obs.	73		73		73		243		243		243	
R2	0.419		0.877		0.8633		0.489		0.792		0.760	
F	4.74	***	25.17	***	22.1	***	12.24	***	98.12	***	81.08	***

Note: Carbon Footprint is measured as the emissions of CO2 tons equivalent per million of income. The explanatory variables are the beta of the excess return of each company to the market factors (MKT, SMB, HML, WML, RMW, CMA, as well as GMP, and industry factors). Left columns are the regressions for US and right columns for Europe. Regressions are performed using the initial (full index) GMP factor, where two portfolios are built using the 10% with less(more) GHG emissions; Columns 2 and 5 represent the regressions using the alternative GMP factors where the portfolios are built using the 10% with less(more) GHG emissions in each industry; Columns 3 and 6 are the regressions using the GMP factors built using the 10% with less(more) GHG emissions in each industry, with half small and half big companies in each industry. The sample only includes companies that are not part of the portfolios used to compute the GMP factor. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance levels.

Taking into account that nowadays many companies are still not reporting (out of lack of regulatory pressure to do so), having an alternative for figuring out the exposition to climate transition risk is quite relevant for investors. To ensure that the GMP beta might play such a role we need to explore the reasons that companies have to do such disclosure. In this sense, we have estimated a Probit analysis on the decision of doing disclosure (Table 5). As can be seen, GMP plays no role on the decision of doing disclosure. This can be interpreted as a sign that companies do not decide to do disclosure or not because they want to show off or hide their carbon footprint. By contrast, the size of the company is the more relevant variable influencing such decision. This is consistent with the relevance of the relative costs of computing and reporting carbon footprints, which would be higher for small companies. In fact, a further signal of the relevance of costs, for Europe the RMW factor has also a positive effect, indicating that companies with more robust profits are more likely to disclose.

Table 5. Probit regression on the decision to disclose CO_2 emissions.

	(19) US Full Index Disclosure		(20) US Industry Disclosure		(21) US Industry & Size Disclosure		(22) EU Full Index Disclosure		(23) EU Industry Disclosure		(24) EU Industry & Size Disclosure	
GMP	-0.107		-0.208	*	-0.181		0.308	*	0.138		0.159	
	(.156)		(.168)		(.358)		(.179)		(.156)		(.164)	
MKT	0.218		0.267		0.301		-0.003		-0.033		-0.097	
	(.467)		(.450)		(.446)		(.338)		(.335)		(.337)	
HML	0.034		0.035		-0.004		-0.034		-0.059		-0.053	
	(.169)		(.163)		(.163)		(.138)		(.138)		(.138)	
SMB	-1.107	***	-1.239	***	-1.153	***	-0.717	***	-0.663	***	-0.653	***
	(.269)		(.273)		(.268)		(.166)		(.162)		(.162)	
RMW	0.241		0.162		0.287		0.303	**	0.280	**	0.288	**
	(.194)		(.192)		(.191)		(.123)		(.125)		(.126)	
CMA	-0.188		-0.166		-0.180		-0.215		-0.227		-0.199	
	(.186)		(.188)		(.188)		(.167)		(.168)		(.174)	
WML	-1.338	**	-1.249	**	-1.391	**	-1.244	***	-1.384	***	-1.357	***
	(.578)		(.575)		(.559)		(.408)		(.399)		(.401)	
Industry Effects	Yes		Yes		Yes		Yes		Yes		Yes	
# obs.	455		455		455		525		525		525	
LR test	45.49	***	49.01	***	46.02	***	54.89	***	52.54	***	52.75	***

Note: Probit regressions for the decision of doing carbon footprint disclosure (1) or not (0). The explanatory variables are the estimated sensitivity (beta) of the excess return of the company to the evolution of each factor in a model with 8 factors (MKT, SMB, HML, WML, RMW, CMA, as well as GMP, and industry factors). Left columns are the regressions for US and right columns for Europe. Regressions are performed using the initial (full index) GMP factor, where two portfolios are built using the 10% with less(more) GHG emissions; Columns 2 and 5 represent the regressions using the alternative GMP factors where the portfolios are built using the 10% with less(more) GHG emissions in each industry; Columns 3 and 6 are the regressions using the GMP factors built using the 10% with less(more) GHG emissions in each industry, with half small and half big companies in each industry. Robust standard errors in parentheses. ***, **, * is the 1%, 5% and 10% significance levels.

A second explanation for the decision of doing disclosure is the investors pressure. For instance, the momentum factor has a negative effect on disclosure. This might be explained for those companies that have worse market performance to disclose their carbon footprint to revert the market sentiment about them. This investors pressure might also explain that companies on those industries with higher CO_2 emissions, are precisely those that are more likely to do disclosure (Fig. 9).

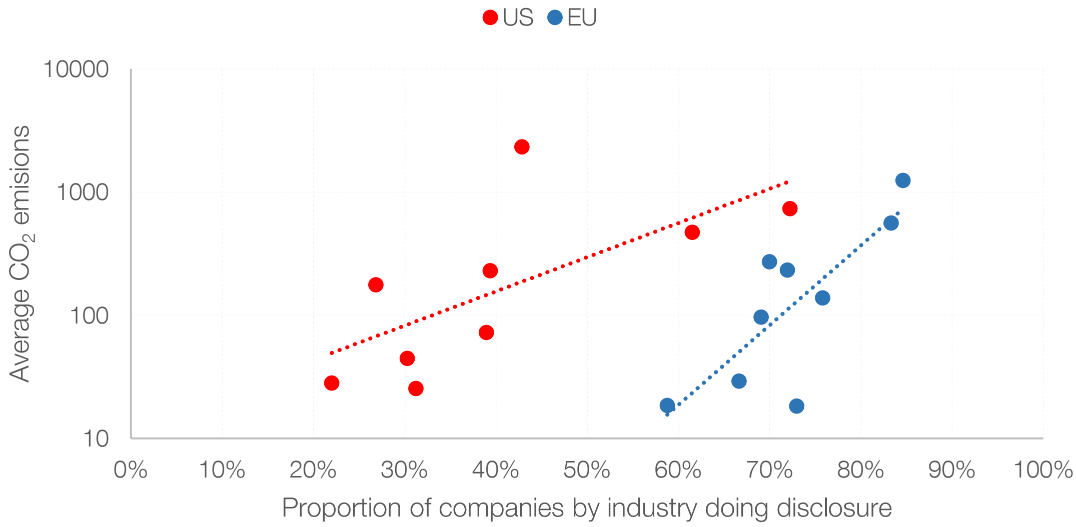

Fig. 9: The proportion of companies doing CO_2 emissions disclosure by industry and economic area (x axis) and average CO_2 emissions by industry (y axis).

5. Conclusions

The relevance of climate related aspects in financial markets is a wave that is being analyzed from different areas. Currently, the regulatory agenda to fight against climate change is broad and will have implications in terms of stablishing specific frameworks to the development of sustainable finance. For instance, it is increasing the development of standards and new requirements on disclosure, such as the requirements under article 8 in the EU taxonomy, the proposal of a Corporate Sustainability Reporting Directive by the European Commission and the European regulation on sustainability-related disclosure in the financial services sector. However, all of these developments will be fully operational in several years' time and financial markets are already taking into account climate-related aspects in its investments.

In this paper we have shown that it is possible to compute a Green Factor (GMP, Green companies Minus Polluters), and that this factor provides relevant information for the investor. This factor explains the stock market excess returns to a similar and even higher extent than other commonly used factors such as WML, CMA or RMW. The Green Factor constructed in this paper also provides very useful information on the exposure of companies to climate change, even if they are not reporting their carbon footprint. In this case, the factor constructed allows to identify the greening of a company which is very relevant nowadays due to disclosure is not mandatory and investors need to know the implication of companies in this regard. And finally it also shows the rising relevance of the factor since the Paris Agreement for investors, with a consistent positive performance of the GMP portfolio, both for US and Europe. In this sense, this paper contributes to identify and compare the evolution of this green factor in both geographical areas where the political decisions regarding climate and the development of regulations have different paces of development.

The presence of a Green Factor implies that financial markets are taking seriously into account the relevance of climate change into their portfolio decisions, showing a preference for companies with lower carbon footprint instead of companies with a higher carbon footprint. Regardless of the reason behind this preference, either because investors are projecting future better performance from a transition to a carbon less economy for the greener companies, or a more proactive engagement of investors in the fight against climate change (Gimeno and Sols, 2020), the consequence is the same, driving higher the prices of greener stocks. As a consequence, companies should take notice of this market preference and have a closer look at their carbon footprint, and how to reduce it, since this would improve the attractiveness of their stocks for investors, and not relegate the sustainability of the company as a mere public relationship operation with no real impact.

The results are also relevant for market practitioners. Currently, disclosure of climate-related aspects and carbon footprint don’t have mandatory and global requirements. In order to incorporate climate change aspects in asset management the availability of data and indicators, both backward and forward looking, is key. Although the pressure to disclose is increasing and regulation will be developed in the next years, nowadays there are companies that don’t report its carbon footprint.

The GMP factor constructed in this paper can be used as a tool to easily establish the Green sensitivity of their portfolio, by just computing their “green beta”. This is especially useful if we take into account the complexity of getting a single value by aggregating the individual carbon footprints of different assets from well diversified portfolios that would necessary include non-reporting issuers, and different degrees of potential “green correlations”. In fact, after the approval of the regulation on sustainability-related disclosures in the financial services sector, in its article 3 states that financial market participants shall publish on their websites information about their policies on the integration of sustainability risks in their investment decision-making process and financial advisers shall publish on their websites information about their policies on the integration of sustainability risks in their investment advice or insurance advice (European Union, 2019), The GMP factor can be also useful also for green rating agencies as a way to double check their green assessment of individual companies, and to fill the gaps to evaluate companies where there is incomplete information.

The main limitations of our research are derived from the scarcity of information. Firstly, there are considerable data gaps, especially for US companies, that force us to construct the green and polluter portfolios with some companies that if we have complete information might not have been in the extremes of the carbon footprint distribution. However, in spite of this problem, we have been able to construct a GMP factor with a sensitivity very well aligned with the carbon footprint for the companies that reported it, a feature that give us confidence that the results would not be that different with a full carbon footprint disclosure situation. In fact, we have shown that the GMP could be a useful tool to fill this data gap which is a relevant utility of the factor constructed in this paper. A second dimension of the data deficiency that affect our analysis is the lack of historical records. The disclosure of carbon footprint has only become an extended practice for companies in recent years. This has forced as to use the carbon footprint of each company at a single point in time (the last data available, to maximize the number of companies with a record). Ideally, we would have need the carbon footprint from the start of the stock prices time series, and allow for recalibrations in the portfolios with the changes in the carbon footprint of each company. However, this is something not feasible to obtain regardless of the efforts of the researchers, because those data do not exist. In fact, we consider that the GMP we have constructed is still a good proxy of the ideal GMP factor, since carbon footprint reductions are very long term efforts (e.g., the targets for carbon footprint reductions established in the international agreements look for very long horizons), and they remain quite stable for very long periods of time.

There are several lines for future research that this paper opens. For starters, the growing interest of investors and policy-makers in ESG factors call for a closer look at the interaction between the GMP factor with the other letters in the ESG framework, such as the governance indexes that are commonly used in the literature (e.g., Gomphers et al., 2003), or the construction of factors that take into account social issues, such as gender balance (e.g., gender pay gap, gender balance in the board of directors), workers protection (e.g., possibilities of unionization, the wage ratio between the top management team and the base workers) or community engagement (e.g., share of income dedicated to social causes). Another line worth exploring is the possible link between the GMP factor with the literature on the presence of a greenium in the fixed income markets (e.g., Bachelet et al. 2019; Baker et al., 2018; Hachenberg and Schiereck, 2018; Larcker and Watts, 2020; Zerbib, 2019). We would expect that the greenium would move in line with the GMP factor if they are capturing similar investor preference for green assets. Other interesting question is if there is a segmentation of investors in line with the GMP, with some of them concentrating in the green subportfolio and other on the polluter subportfolio. This would go in line with Martin and Moser (2016) assessment that some investors might trade off returns for social concerns. Data on asset holdings are limited, but the SHSS (Securities Holding Statistics by Sectors) maintained by the European System of Central Banks (Koijen et al., 2017) would allow to study this possibility for the EU portfolios. In line with this potential trade off, it would be interesting to analyze the potential effect of the existence of a GMP factor on the cost of equity of the greener companies, as predicted by Dhaliwal et al. (2011). Also, and in line with the stability of the reported carbon footprint of companies, it would be interesting to use event studies on the announcement of carbon footprint reductions, and the other way around, study the credibility of these announcements by the market, in terms of green washing (Laufer, 2003). This could be especially relevant now that use of proceed bonds are being replace in the market by performance-linked bonds that implies that the managers put their money at risk of no compliance, that would increase the credibility given by market participants, and therefore, the market impact of the commitments.

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Annex: The Green Extended Factor Model

We start from the classical CAPM model of Sharpe (1964), Lintner (1965) and Black (1972),

$$R_{it} - Rf_t = \alpha + \beta(E[Rm_t] - Rf_t) + e_{it} \tag{A1}$$

where the excess return of a company *i* on day *t* (R_{it}) over the risk-free rate (Rf_t), depends on the expected excess return of the market portfolio ($E[Rm_t] - Rf_t$), and the risk level of the company, also known as the company β. Further extensive research of Fama and French (1995; 1996; 1998) expanded this initial model, using a perspective from the factor analysis/principal components framework to include additional factors influencing the cross-sectional variation of stock returns. In a principal component decomposition, one would generally get a first component that would be approximately an average of each of the variables included, as is the case of the market factor in equation A1. The following components would be orthogonal on this first factor, and one would get that if the component has a positive correlation with some of the variables and a negative correlation with some other ones. This is precisely the way Fama and French (1993) used to build their 3 factor model (equation A2):

$$R_{it} - Rf_t = \alpha + \beta(E[Rm_t] - Rf_t) +$$

$$+\gamma_{SMB}\left(S_{MS,t} - B_{MS,t}\right) + \gamma_{HML}\left(H_{\frac{B}{M},t} - L_{\frac{B}{M},t}\right) + e_{it}. \tag{A2}$$

The new factors are constructed around the Market Size (MS) and the Book to Market ratio (B/M) of the companies. In the case of the market size, they create a factor that is positively correlated with the return of small companies and negatively correlated with the return of big companies. They get that by constructing a portfolio that goes long on small companies and short on big companies. This way of creating the portfolio (i.e., going long on some companies, and short on others) ensures the orthogonality of the SMB factor with the market factor, and have a clear meaning (i.e., long small companies, short big companies). In the same vein, they propose a second factor that uses the Book-to-Market ratio of each company to sort them. Hence, they construct a portfolio that goes long on companies with high book-to-market ratios, and short on companies with low book-to-market ratios (hence the name of High Minus Low book to market, HML).

Carhart (1997) added a fourth factor to the Fama and French (1993) 3 factor model: the momentum, where the portfolios used were created grouping those companies that had higher returns in the past, and those which had lower returns (hence the name Winners Minus Losers, WML),

$$R_{it} - Rf_t = \alpha + \beta(E[Rm_t] - Rf_t) +$$

$$+\gamma_{SMB}\left(S_{MS,t} - B_{MS,t}\right) + \gamma_{HML}\left(H_{\frac{B}{M},t} - L_{\frac{B}{M},t}\right) +$$

$$+\gamma_{WML}\left(W_{MOM,t} - L_{MOM,t}\right) + e_{it}. \quad \text{(A3)}$$

Fama and French (2015) proposed a 5 factor model, building on the Fama and French (1993) 3 factors model, by adding two new factors, based on profits and investment. This way, they proposed two new ways to build a portfolio, going long on companies with robust profits, and short on those companies with weak profits (hence the name of Robust Minus Weak, RMB); and going long on those companies with conservative investments, and short on those companies with aggressive investment strategies (hence the name of Conservative Minus Aggressive, CMA). The five factors model is presented in equation A4,

$$R_{it} - Rf_t = \alpha + \beta(E[Rm_t] - Rf_t) +$$

$$+\gamma_{SMB}\left(S_{MS,t} - B_{MS,t}\right) + \gamma_{HML}\left(H_{\frac{B}{M},t} - L_{\frac{B}{M},t}\right) +$$

$$+\gamma_{RMW}\left(R_{PROF,t} - W_{PROF,t}\right) + \gamma_{CMA}\left(C_{INV,t} - A_{INV,t}\right) + e_{it}. \quad \text{(A4)}$$

Using the same reasoning, the literature has proposed several other possible factors to be considered, although the ones we have shown are the most commonly and widely used. In line with them, we construct a new factor that takes into account the exposure of a company to climate change, and specifically to the transition risks of climate change. In this sense, with the pressure of governments for action on climate change (especially after the Paris Agreement), investors are increasingly monitoring the CO_2 emissions of companies, since those with higher emissions would be subject to regulatory measures, as well as potential carbon taxes/credits, that would affect their profitability. In fact, Krueger et al. (2020) find in a survey on institutional investors that they consider that regulatory climate risks have begun to materialize. Thus, there is a potential validity for a valuation factor of companies that takes into account the CO_2 emissions disclosed, building a portfolio that goes long on greener companies, and short on the polluter ones (hence, we propose the name of Greeners Minus Polluters, GMP). A model that enclosed the previous equations 3 and 4, as well as the GMP factor would be as the one in equation A5,

$$R_{it} - Rf_t = \alpha + \beta(E[Rm_t] - Rf_t) + \gamma_{WML}(W_{MOM,t} - L_{MOM,t}) + \\ + \gamma_{SMB}(S_{MS,t} - B_{MS,t}) + \gamma_{HML}\left(H_{\frac{B}{M},t} - L_{\frac{B}{M},t}\right) + \\ + \gamma_{RMW}(R_{PROF,t} - W_{PROF,t}) + \gamma_{CMA}(C_{INV,t} - A_{INV,t}) \\ + \gamma_{GMP}(G_{CO2,t} - P_{CO2,t}) + e_{it}. \quad \text{(A5)}$$