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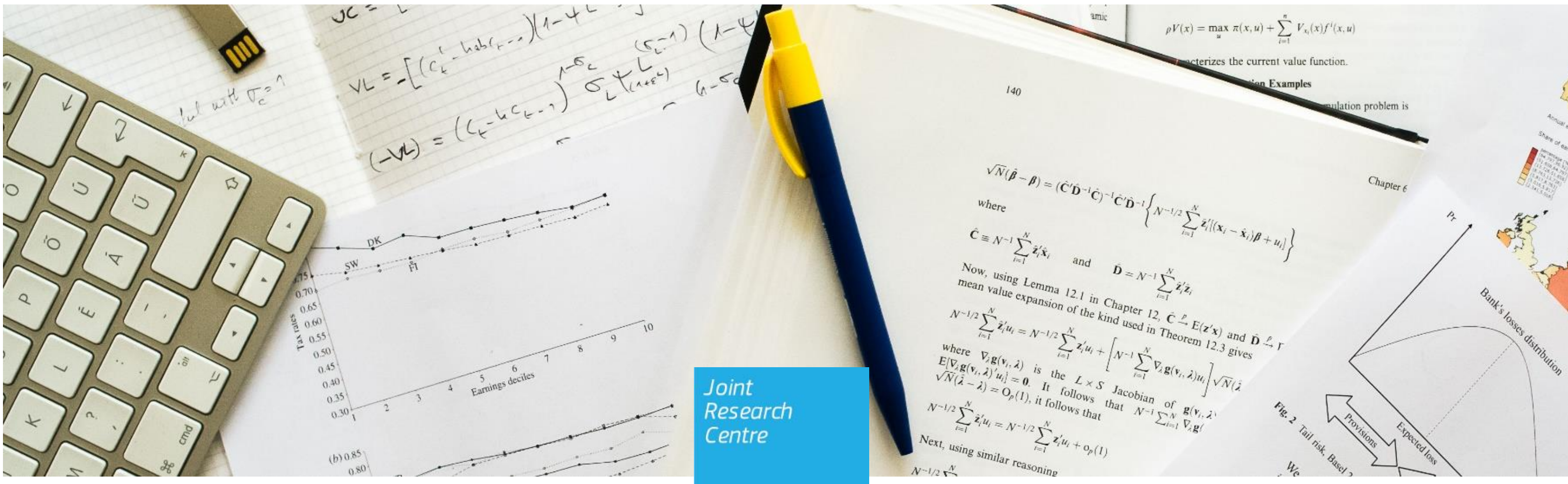

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The Greenium matters:
evidence on the pricing of climate risk

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Abstract

This study provides evidence on the existence of a negative Greenium, i.e. a green risk premium, based on European individual stock returns and portfolios. By defining a green factor which is priced by the market, we offer a tool to assess a portfolio exposure to climate risk and hedge against it. We estimate that even in a rather benign scenario, there would be losses at the global level, including for European large banks, should they fail to price the Greenium. By halving the exposure to carbon-intensive sectors, losses would be reduced by 30%. These results call for the introduction of carbon stress tests for systemically important institutions.

Keywords: Climate risk, ESG disclosure, factor models, asset pricing, stress test.

J.E.L. classification: G01; G11; G12; Q01.

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1 Introduction

Climate change is a fact, but we are not sure what the economic costs associated with this change will be.[1] By the same token, it is difficult to estimate what the economic benefits of doing something about it would be. In particular, it would be hard to pin down the net present value of activities aimed at climate change adaptation and mitigation, as well as those directed to broader environmental objectives such as the sustainable use and protection of water and marine resources, the transition to a circular economy, waste prevention and recycling, pollution prevention and control, as well as the protection of healthy ecosystems.[2] The first contribution of this paper is to measure the added value of green economic activities in terms of market excess returns.

At the same time, the consequences of a transition to a low-carbon, resource-efficient and circular economy, or lack thereof, are also largely uncertain. Hence, these issues have to be addressed as aspects of long-run risk. The second contribution of this paper is to show that indeed, the market prices climate risk and associates a negative risk premium, which we label Greenium, to more environmentally friendly activities. In other words, we show that investors accept a lower remuneration for their investments, *ceteris paribus*, in so far as these investments are linked to more sustainable economic activities.

We identify the green factor based on a precise definition of green. In particular, we first construct portfolios characterized by different shades of green. This is done based on a careful assessment of the sustainability of individual companies. In particular, we use firm-level information on greenhouse gas (GHG) or CO2 emissions, combined with a measure of the completeness of such information, to yield a synthetic greenness index for each stock. Companies which disclose comparably low levels of emissions, and are very transparent, attain the highest scores and are included in a green portfolio. The most straightforward example of green companies would be those with a large share of their turnover in green economic sectors, e.g. renewable energy. Conversely, companies which do not disclose ESG information are labeled as non transparent. Among these nontransparent companies, those active in carbon-intensive sectors, e.g. companies operating coal power plants, are included in a brown portfolio. Our analysis is based on 1,230 companies listed on the STOXX Europe Total Market Index.

By relying on company-level disclosures and factoring-in their transparency, we overcome the issue of greenwashing, which is likely to be the reason why the literature has so far failed to find evidence of a priced green factor. Indeed, looking at the actual composition of the portfolios of publicly traded investment funds which label themselves as 'green' or 'sustainable', it turns out that many funds are clearly less environmentally friendly than their name would suggest. For example, a fund might indeed limit its exposure to carbon-intensive sectors, but at the same time mainly invest in e.g. financial stocks. Banks, insurers and other financial institutions are admittedly

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[1] On the uncertainty on the rate of increase in average temperatures in the long-medium horizon, and on the effects of climate change, see Pindyck (2013).

[2] These objectives are listed in the European Commission Action plan on financing sustainable growth, which sets out an EU strategy for sustainable finance. Notice that sustainability refers to three broad dimensions, namely environmental, social and governance (ESG). Environmental aspects, in turn, comprise both climate change and other aspects. In this paper we focus on climate change, but will use the broader term 'green' for ease of exposition.

directly responsible for a very small fraction of greenhouse gas (GHG) emissions, but HSBC or Allianz is probably not what comes to mind when thinking of a company that is at the forefront of efforts to reduce emissions.

So-called 'green' funds might as well happen to invest some share of their portfolio in 'brown' companies, which is something an environmentally-minded investor would probably not be happy about. In this respect, however, one should be careful not to take extreme views. As a matter of fact, portfolio diversification is crucial for asset managers, and concentrating the exposure on a small set of pure green players is not a viable option. At the same time, our society will still need e.g. steel and cement for quite a while. Moreover, companies' low-carbon transition is a much needed but gradual process. For all these reasons, a sensible approach would be to broaden the scope of the definition of 'green' beyond pure players to also include firms that meet the highest level of energy efficiency and the lowest CO2 emissions within the relevant sector. By taking this approach, a steel manufacturer which also uses scrap steel would be greener than one that does not. By the same token, an energy company that reduces its reliance on fossil fuels – though not having an entirely renewable energy mix – would be greener than one that is not reducing its carbon footprint. This is the approach taken by several providers of ESG scores, which assess the sustainability of firms relative to their peers, and also the one we take in this paper.

Based on this methodology we construct a (time-varying) green portfolio and show that it has outperformed the brown portfolio over the last 10 years. This is evidence of future climate risks being seen as more severe. Indeed, in a scenario of heightened risks resulting from climate change, there would be a stronger push towards more environmentally friendly activities, with more decisive political action likely to be taken to promote sustainable growth. Hence, companies active in green sectors would operate in a more favorable environment, possibly supported by incentives, e.g. fiscal or of other nature. At the same time, the likelihood would increase that some assets, e.g. coal, would become stranded. As a result, green companies yield positive future excess returns compared to non green ones, all else being equal. In this context, forward-looking investors who base their portfolio allocation on expected returns invest in green assets already today. In other words, we find evidence of climate risk being viewed as significant, with the market seeing value in investing in green assets as a hedging strategy towards worse environmental outcomes.

We also show that in the context of a standard asset pricing model, the green portfolio is associated with a lower loading on the market risk factor and a positive alpha, suggesting the existence of an omitted factor. Based on this evidence, we propose to include a green factor, which we construct based on a long-short strategy involving the green and brown portfolios. We find that the Greenium, i.e. the risk premium associated with this green factor, is negative and significant.

The evidence we provide on the outperformance of green portfolios and on the existence of a Greenium has clear financial stability implications. Indeed, we show that investors who do not factor in climate risk in the construction of their portfolios are in fact pricing their holdings based on a misspecified model. Should this mispricing affect the assets held by systemically important financial institutions (SIFIs) such as large banks, insurers and pension funds, there could be consequences in terms of systemic risk. In particular, asset returns on their holdings could be negatively affected by climate change via two main channels. First, in a longer horizon perspective, more frequent and severe natural catastrophes stemming from climate change (e.g. typhoons and floods) could negatively affect returns on assets linked to particularly vulnerable economic activities.[3] In this respect, it has been shown that rising temperatures have strong adverse effects on key macroeconomics aggregates and productivity, on top of asset valuations (see Donadelli et al., 2017). Second, in a medium-term perspective, the implementation of sustainable finance policies will imply higher costs for firms with higher emissions, causing a generalized drop in the dividend that brown firms will be able to pay to their shareholders. In parallel, carbon-intensive assets will increasingly become 'stranded' (see Campiglio et al., 2017). These two channels characterize an environmental risk factor that investors should price. Given the lack of data on the exposure of individual companies to physical risks related to climate change, in this analysis we will focus on transition risks, i.e. the potential impacts of a shift to a lower carbon-footprint economy on firms active in climate-policy-relevant sectors.

Based on our model, we estimate that even in a non-extreme scenario, all institutional sectors at the global level, including e.g. governments, non-financial institutions and financial corporations, as well as all European SIFIs, would be hit by losses. By halving their exposure to carbon-intensive sectors and reallocating their investments towards greener assets, they could reduce the loss by 30% compared to the baseline. The magnitude of the expected losses we estimate is not particularly large, when we test a very mild and plausible scenario. Still, we show that no one is in a safe place when it comes to climate risk, as the consequences of brown asset mispricing would be widespread. Moreover, we show that losses would amount to 1 tn globally, and 30 bn for European SIFIs only, under a more extreme but still plausible scenario. This could have serious implications in terms of financial stability, especially if coupled with shocks of other nature. Moreover, we only estimate losses from equity exposures, i.e. not considering fixed-income markets and notably, banks' loan exposure. Hence, we argue that a carbon stress test is warranted for systemically important institutions to monitor their resilience to climate change. The green factor we construct could indeed be used by investors, to hedge against climate risk, and by supervisors, to measure SIFIs exposure to this risk. Notice that we can only expect the Greenium to increase in the future, along with greater policy pressure to reducing carbon emissions and moving to a sustainable development path.[4]

The paper is structured as follows. In the next section, we provide an overview of the relevant literature. In Section 3, we present our synthetic 'greenness' indicator at the level of the individual company. Section 4 outlines the asset pricing model that we estimate. In Section 5, we present the results of the empirical application. First, we focus on portfolios. Then, we provide results on individual stocks. Section 6 tests the performance of the equity portfolios of global institutional sectors and European SIFIs in a carbon-stressed scenario. Section 7 concludes.

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[3] Daniel et al. (2016).

[4] Andersson et al. (2016) shows that divestment in higher emission stocks entails a cost, which investors are more likely to bear the stronger the perception of a serious commitment on the side of policymakers towards fighting climate change.

2 Related literature

This paper stands at the crossroad of sustainable finance, asset pricing and financial stability. The sustainable finance literature has so far mostly focused on corporate performance, starting from the seminal work by Bragdon and Marlin (1972). They asked the fundamental question, whether there would be a reward for a company's virtue. Trying to answer this question, Margolis et al. (2009) finds a small and positive relationship between corporate social performances and financial performance. Along these lines, Porter (1991), Gore (1993), and Porter and van der Linde (1995) argue that improving a company environmental performance can lead to a better economic or financial performance, not necessarily accompanied by an increase in costs. Ambec and Lanoie (2008) review several empirical works showing that improvements in the environmental performance of a firm tend to be associated with improvements in the economic or financial performance, owing to potential revenue increases and/or cost cuts. More recently, Hoepner et al. (2018) show that engagement on sustainability issues can benefit shareholders' by reducing firms' downside risks.

Despite increasingly available evidence on the performance of green or sustainable corporates, however, no consensus has yet been reached in the asset pricing literature about the performance of green assets, or on environmental risk being a priced macro factor. Evidence based on a large number of studies on the performance of sustainable investment funds compared with conventional peers (e.g., Statman, 2000; Renneboog et al., 2007; Seitz, 2010) is mixed. For example, Hartzmark and Sussman (2018) find that sustainability is viewed as positively predicting future performance; however, they do not find evidence of outperformance of 'high sustainability' investment funds vs 'low sustainability' ones. Trinks et al. (2018) show that divesting in carbon fossil stocks does not impair portfolio performance. Derwall et al. (2005) find that more socially responsible portfolios provide higher average returns. On the contrary, Bolton and Kacperczyk (2019) find that stocks of companies with higher CO2 emission intensity earn higher returns. Other analyses based on publicly traded environmental portfolios find that green stocks are, on average, underperforming the market. This finding would indicate that investors are willing to earn comparatively less on these assets because they are hedging an environmental long-run risk. Finally, recent papers attempt to build climate risk hedging portfolios (see Engle et al., 2019, Choi et al., 2018, Hong et al., 2019, Kumar et al., 2018 and Goergen et al., 2019, Monasterolo and De Angelis, 2019); however, none of these works goes all the way to quantifying the associated risk premium.

Finally, the financial stability literature has started to put forward the idea of 'carbon stress tests' on the exposures of financial institutions (see Battiston et al., 2017 and Battiston and Monasterolo, 2018), as well as to develop climate stress-test methodologies for e.g. loan portfolios (see Monasterolo et al., 2018). Central Banks and international institutions, starting with the seminal speech by Carney (2015), have also emphasized on different occasions that climate change could affect systemic risk. In particular, Gros et al. (2016) distinguishes between a benign scenario, with a gradual transition to a low-carbon economy, and an adverse scenario, where the transition occurs more abruptly. In both cases, there could be financial stability consequences: with a too slow transition, the Paris Agreement goal would be missed and the catastrophic consequences of climate change would become unavoidable.[5] A too quick transition, on the other hand, would imply a sudden repricing of brown assets. We provide evidence that these concerns are shared by the market.

3 Synthetic greenness indicator

Different indicators are available to assess a company's commitment to sustainability. Investors could in principle use this information to distinguish companies that are really doing sustainable business from firms that are not transparent in this respect. However, a single indicator might not be sufficient to ensure a careful assessment of a company's sustainability, in particular with respect to its environmental performance, including its emissions.

We focus on the Bloomberg ESG disclosure score, which is an index quantifying the completeness of a firm's disclosure in terms of impact on the environment, social projects, and corporate governance. The ESG disclosure score embraces several aspects of a firm's business. In particular, it covers environmental aspects by looking at how a company performs with respect to carbon emissions, air and water pollution, protection of biodiversity, and waste management, among others. Social issues include for example labor standards and human rights. The governance dimension concerns a company's leadership, executive pay, audits, internal controls and shareholder rights. The weighted ESG score is normalized to range from zero for companies that do not disclose ESG data to 100 for those which disclose detailed information for each pillar. The score is also tailored for industry sectors, and each component is weighted based on its importance. In particular, GHG emission disclosure is attached the highest weight.

We use the ESG disclosure score as a measure of the transparency of a firm with respect to its sustainability commitment, and assume that higher commitment is associated with higher transparency. In other words, based on the ESG score, we make a first selection among firms that are transparent, at least to some extent, about their ESG performance, and firms that are not. We do not claim that firms that do not disclose ESG information, and in particular information on the "E", are necessarily ecologically destructive. However, we find it legitimate to label them as non-green, as their environmental commitment appears weaker compared to firms that do disclose (quantitative) information on this pillar. Among non-transparent firms, we further select a subsample that we label 'brown'. These are companies which are mainly active in sectors characterized by a comparatively higher level of carbon emissions.

To build a comprehensive index of a company's environmental performance, we combine this transparency measure with quantitative disclosure on emissions. In particular, we consider the Total Greenhouse Gas (GHG) Emission intensity per sales. If this is not available, we take the total carbon dioxide (CO2) emitted, measured in metric tonnes, weighted for sales revenues.

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[5] The objective of the Paris Agreement, signed in 2015, is to keep a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

Formally, the synthetic 'greenness' indicator $G_{i,y}$ of company i at year y is defined as follows:

$$G_{i,y} = \frac{ESG_{i,y}}{K_{i,y}} = ESG_{i,y} \left(\frac{Sales}{Emissions} \right)_{i,y}, \tag{1}$$

where $ESG_{i,y}$ is the ESG score and $K_{i,y}$ is the ratio of total GHG or CO2 emissions over sales. More transparent companies, with a lower intensity of GHG or CO2 emissions, are associated with larger values of the indicator $G_{i,y}$. Figure 1 shows the greenness indicator, the ESG score and the emission intensity for two representative companies included in our sample, belonging to two different economic sectors. NIBE industrier AB, in panel A, is develops solutions for smart heating and intelligent control in industry and infrastructure. International Airlines Group, in panel B, is the largest airline group globally. The greenness indicator for the two companies differs by three orders of magnitude. Moreover, the quality and quantity of ESG disclosures has improved over time for the company in panel A, together with a decreasing emission intensity, both resulting in an increasing value for the greenness indicator over time. The company in panel B attained an ESG score in 2011 which was comparable to that of the company in panel A in 2009. However, the ESG score only marginally improved over time for company B. Also the level of emission intensity did not dramatically improve over the years, as reflected in the overall greenness indicator, remaining at levels that are obviously incomparably higher for airlines than for other companies.

Figure 2 shows the number of companies in our sample which did some ESG disclosure, from 2005 to 2017. The orange bar shows the number of firms for which the ESG disclosure score is different from zero in a given year, i.e. those that did some ESG disclosure. The gray bar represents the number of firms that in a given year disclosed their emission intensity. Finally, the yellow bar corresponds to the number of firms for which the greenness indicator can be derived in a given year. The share of companies reporting on the "E" has increased in the last ten years, to almost reach 100% of the companies reporting on ESG as a whole. However, this increase in the share of companies reporting on their emissions has coincided with a huge drop of the total number reporting on ESG in 2017.

4 Linear factor model

The asset pricing model we use assumes an approximate factor structure for excess returns. This is combined with the absence of arbitrage opportunities to obtain asset pricing restrictions. As the greenness indicator defined in Equation (3) is only available for a relatively short sample, we opt for a time-invariant model, which assumes that the exposition of an asset i to each observable factor does not evolve over time. In particular, the model proposed is a specific case of the more general conditional linear factor model with a continuum of assets introduced by Gagliardini et al. (2016) (GOS).[6] The general framework in GOS covers both settings for individual stocks and portfolios, as the approximate factor structure is invariant to asset repackaging.

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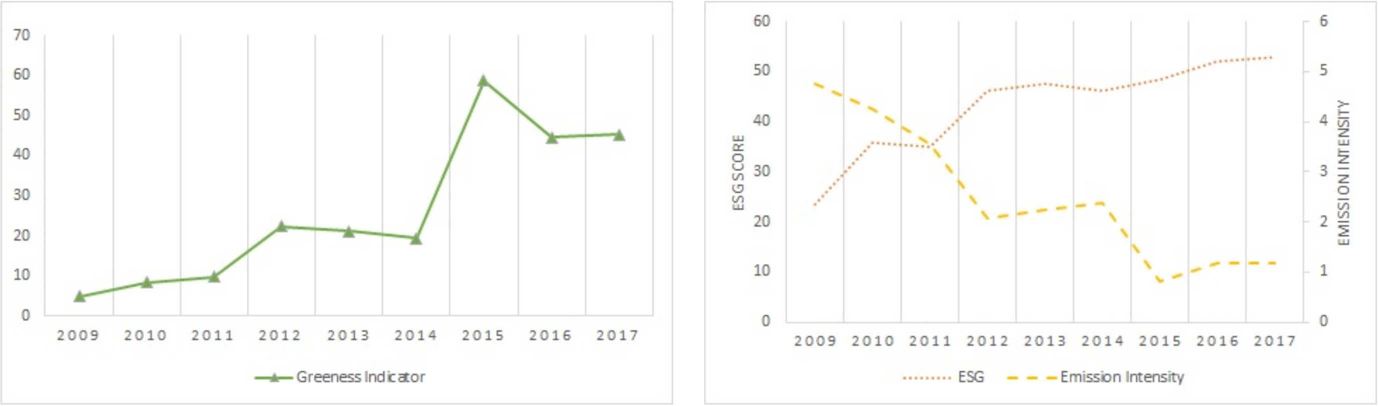
[6] We refer to GOS for theoretical results and proofs.

PANEL A: NIBE Industrier AB



PANEL B: International Airlines Group

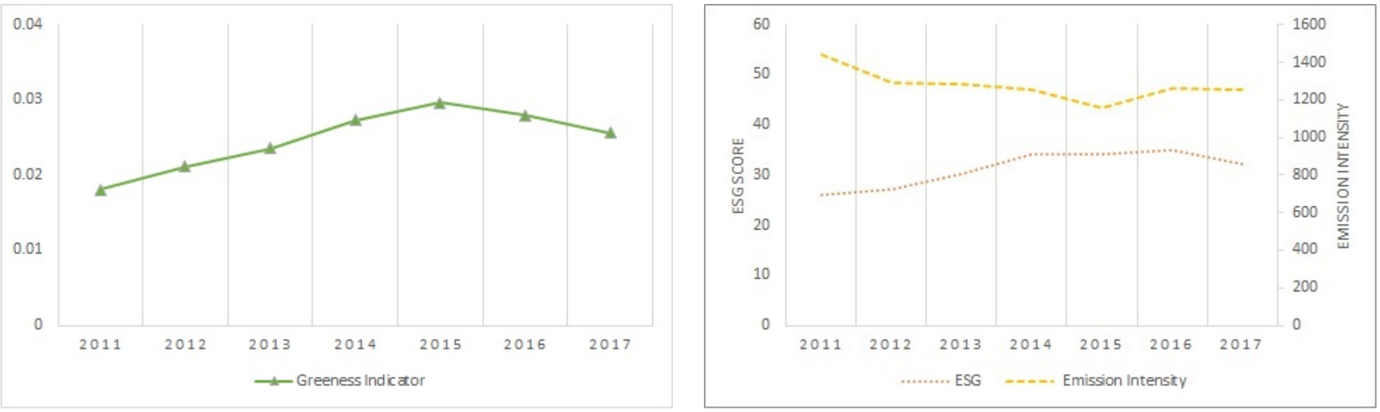


Figure 1: Greenness indicator, ESG score and emissions intensity for two representative firms.

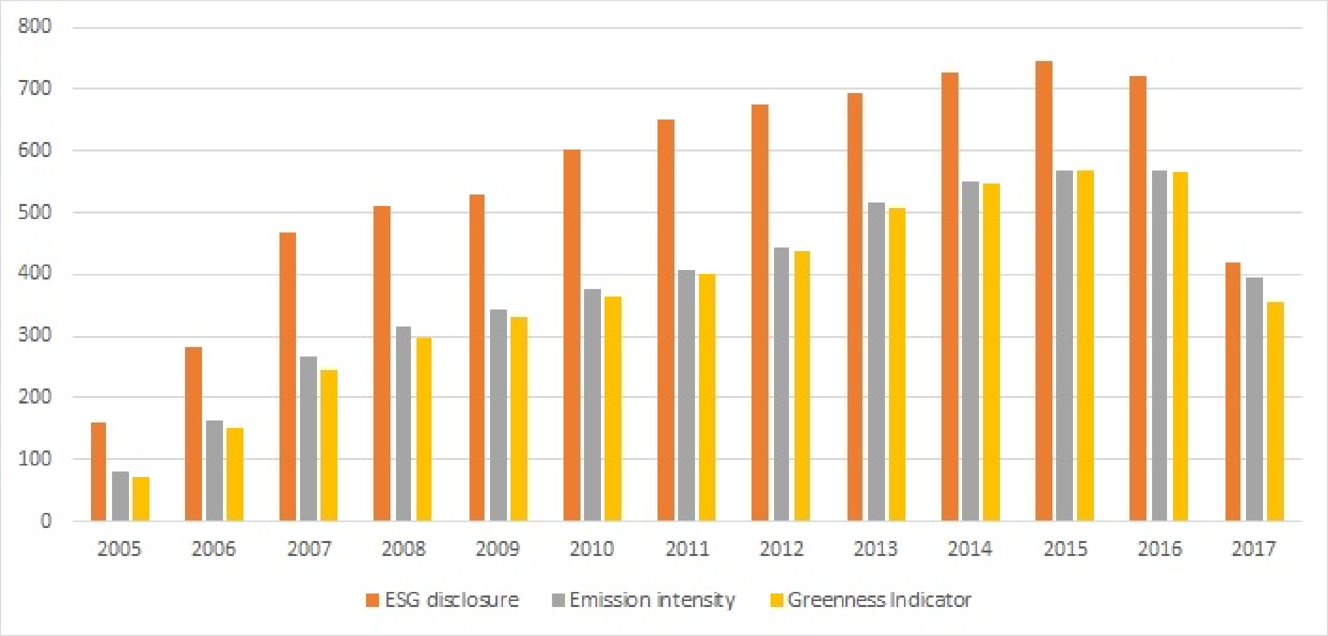


Figure 2: Total number of companies for which the ESG disclosure score, the emissions intensity per sales ratio, and, thus, the greenness indicator is available and differs from zero.

We assume that the excess returns $R_{i,t}$ of asset $i = 1, ..., n$, at date $t = 1, 2, ...T$ satisfy the following linear factor model:

$$R_{i,t} = a_i + b_i' f_t + \varepsilon_{i,t}, \tag{2}$$

where f_t is a vector of K observable factors, the error term $\varepsilon_{i,t}$ is s.t. $E[\varepsilon_{i,t}|\mathcal{F}_{t-1}] = 0$, and $Cov[\varepsilon_{i,t}, f_t|\mathcal{F}_{t-1}] = 0$. $\mathcal{F}_{t-1}$ is the lagged information set. The approximate factor structure holds for the variance-covariance of the error terms, i.e., $\Sigma_{\varepsilon,t,n} = [Cov[\varepsilon_{i,t}, \varepsilon_{j,t}|\mathcal{F}_{t-1}]]_{i,j=1,...,n}$ with bounded largest eigenvalue (see, e.g., Chamberlain and Rothschild, 1983). The following asset restriction holds:

$$a_i = b_i' \nu, \tag{3}$$

where ν is a K vector. The asset pricing restriction in Equation (3) can be rewritten as the usual linear relation between expected excess returns and risk premia, i.e., the financial compensation asked by investors for bearing systematic risk:

$$E[R_{i,t}] = b_i' \lambda, \tag{4}$$

where $\lambda = E[f_t] + \nu$. Thus, the risk premium is defined as the sum of the first moment of the observable factors f_t plus the coefficient ν, defined in the asset pricing restriction (3) and accounting for the cross-sectional properties of excess returns.

Our baseline asset pricing model is the five-factor model proposed in Fama and French (2015), with $f_t = (r_{m,t}, r_{smb,t}, r_{hml,t}, r_{rmw,t}, r_{cma,t})'$, where $r_{m,t}$ is the month t excess return on the European value-weighted market portfolio over the risk free rate, and $r_{smb,t}$, $r_{hml,t}$, $r_{rmw,t}$, and $r_{cma,t}$ are the month t returns on zero-investment factor-mimicking portfolios for size, book-to-market, profitability and investment (see Fama and French, 1993, 2015). These factors are built as a combination of portfolios composed by ranked stocks and available historical data. The size factor $r_{smb,t}$ is the average return of small stock portfolios minus the average return of big stock portfolios. The value factor $r_{hml,t}$ is the average return of the value portfolios minus the average return of the growth portfolios. A value portfolio is composed by value stocks that have market value that is small relative to the book value. The profitability factor $r_{rmw,t}$ is the average return of the robust operating profitability portfolios minus the average return of the weak operating profitability portfolios. The operating profitability is defined as revenues minus cost of goods sold, minus selling, general and administratives expenses, minus interest expense all divided by book equity. The investment factor $r_{cma,t}$ is the average return of the conservative investment portfolios minus the average return of the aggressive investment portfolios. The investment is measured through the growth rate in total assets. We also consider the momentum factor $r_{mom,t}$, i.e., the equal-weight average of the returns for the winner portfolios minus the average of the returns for the loser portfolios (see Carhart, 1997). We proxy the risk free rate with the monthly 30-day T-bill beginning-of-month yield. The time series of European factors and the risk free rate are available on Kenneth French's website.

5 Empirical analysis

In this section, we provide evidence on the performance of green and brown portfolios. Based on these portfolios we build an observable green factor. Then, we estimate the Greenium, i.e. the risk premium for the green factor, using: i) a set of European individual stocks and, ii) the 25 European Fama-French portfolios.[7] We test both settings as, unlike portfolios, individual stocks also provide cross-sectional information (see Lewellen et al., 2010 for a discussion about how the construction of portfolios distorts cross-sectional heterogeneity).

Our sample spans from January 2005 to August 2018, covering all individual stocks included in the STOXX Europe Total Market Index (TMI) on August 2018. The STOXX Europe TMI covers approximately 95% of the free float market capitalization across 17 European countries.[8] We exclude financial firms (i.e., assets associated with NACE codes K and L) as in Fama and French (2008). The final dataset comprises $n = 942$ stocks with $T = 153$ monthly observations. Monthly stock returns and stock market capitalization data are sourced from Bloomberg. The panel is unbalanced, i.e., asset returns are not available for all firms at all dates.

We compare the green portfolios we build with the FTSE4Good Europe Index from Bloomberg. This index is designed to measure the performance of companies that meet corporate responsibility standards.[9] The FTSE4Good index selects stocks based on the FTSE Russell's ESG ratings and excludes companies involved in weapons, tobacco

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[7] Available at `http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html`.

[8] These are Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

[9] See `www.ftse.com` for a detailed description.

and coal mining activities.

5.1 Portfolio analysis and the Green Factor

Based on the definition of the greenness indicator in Equation (1) we distinguish between transparent companies, i.e., the ones included in $\mathcal{G} = \{i \in \Omega \text{ s.t. } G_{i,y-1} \neq 0\}$, and non transparent companies, included in $\mathcal{G}^c = \{i \in \Omega | i \notin \mathcal{G}\}$. Based on this distinction, at each month $t \in y$ where y is year; we define the transparent and non-transparent portfolios, respectively, as follows:

$$\tilde{R}_t = \sum_{i \in \mathcal{G}} w_i R_{i,t}, \quad \text{and} \quad \tilde{\tilde{R}}_t = \sum_{i \in \mathcal{G}^c} w_i R_{i,t}, \tag{5}$$

where $w_i = MC_{i,t} / \sum_t MC_{i,t}$, and $MC_{i,t}$ is the market capitalization of stock i at month t. Furthermore, in order to analyze the performance of transparent portfolios based on their shades of green, we build the following quintile portfolios:

$$\tilde{R}_{q,t} = \sum_{i \in \mathcal{G}^p} w_i R_{i,t}, \text{ with } q = 1, ..., 5, \tag{6}$$

where $\mathcal{G}^p = \{i \in \mathcal{G} : i \in Q(p)\}$ and $Q(p) = \{\inf_i \{G_{i,y-1} : p \leq F(G_{i,y-1})\}\}$ for a probability $p \in [0, 1]$, and a distribution function $F(.)$. The portfolio built on the the fifth quintile, i.e. $\tilde{R}_{5,t}$, includes stocks in firms ranking high with respect to the greenness score and is labeled 'green' portfolio. We also build the brown portfolio $\tilde{\tilde{R}}_{b,t}$, including stocks in those companies among $\mathcal{G}^c$, which are active in one or more of the industries with highest emissions. Figures 3 and 4 show the time-varying asset allocation by NACE sector of the green and brown portfolios, respectively. Manufacturing is the most represented sector in both portfolios. However, manufacturing firms belonging to the green portfolio are by definition much more transparent than those included in the brown portfolio.

Table 1 reports descriptive statistics for yearly returns for the various portfolios. Transparent portfolios $\tilde{R}_{q,t}$, with $q = 1, ..., 5$, yield positive returns on average. Their volatility decreases for lighter shades of green. Indeed, statistics for the lowest quintile portfolio $\tilde{R}_{1,t}$ are comparable to the ones for the non transparent portfolio $\tilde{\tilde{R}}_t$. Returns are characterized by excess kurtosis and negative skewness. The table also reports the Sharpe ratio (Sharpe, 1964, 1994), that measures the average return earned in excess of the risk-free rate per unit of volatility or total risk. The Sharpe ratio is largest for the green portfolio, i.e., portfolio $\tilde{R}_{5,t}$ generates a higher return on a risk-adjusted basis w.r.t. other portfolios. For the sake of comparison, we report results for the FTSE4Good Europe index, which is characterized by a non-significant mean return. Figure 5 shows paths of cumulative returns for the green and brown portfolios, i.e. how much a hypothetical investment done in 2006 in a specific portfolio would have yielded by August 2018. The green portfolio outperforms the brown portfolio, with a cumulative return of 20% compared to 12%. The figure also shows paths of cumulative returns for the STOXX Europe TMI and the FTSE4Good index. The green portfolio is associated with a better financial performance compared to the indexes as well.

Figure 3: Asset allocation of the green portfolio by industry. Industry NACE codes: manufacturing (C); information and communication (J); wholesale and retail trade, repair of motor vehicles and motorcycles (G); transportation and storage (H); electricity, gas, steam and air conditioning supply (D).

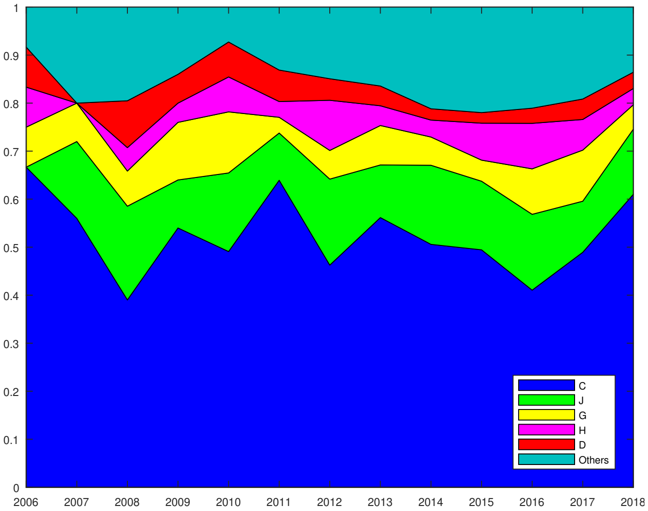


Figure 4: Asset allocation of the brown portfolio by industry. Industry NACE codes: manufacturing (C); transportation and storage (H); electricity, gas, steam and air conditioning supply (D); agriculture, forestry and fishing (A); mining and quarrying (B).

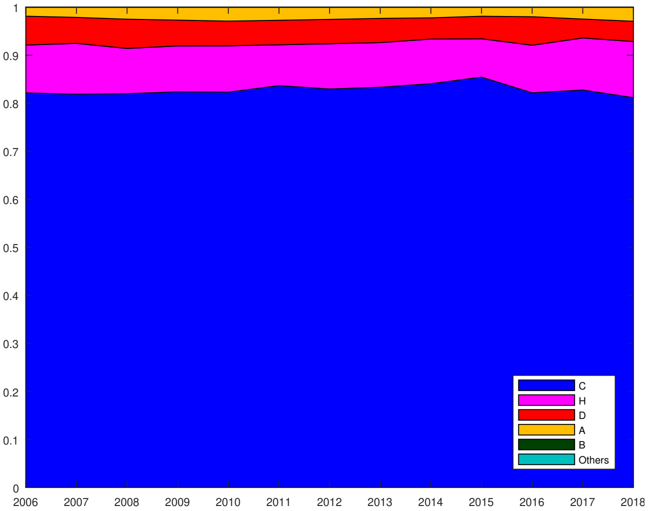
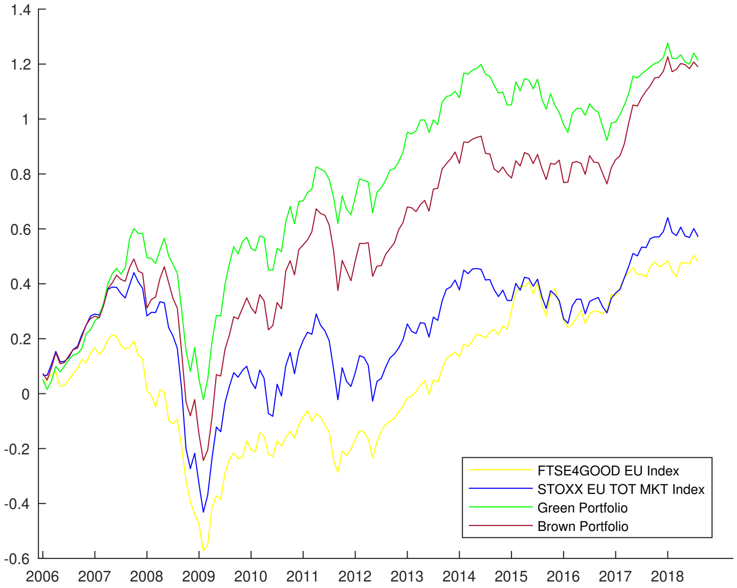


Table 1: Descriptive statistics of portfolio returns. The table reports the yearly mean and standard deviation, kurtosis and skewness, the Sharpe ratio, and t-stat for the null hypothesis that the mean return is zero.

Portfolio	Mean	Std	Kurtosis	Skewness	Sharpe	t-stat
$\tilde{R}$, Transparent portfolio	0.089	0.175	3.908	-0.549	0.130	1.821
$\tilde{\tilde{R}}$ Non-transparent portfolio	0.098	0.185	4.544	-0.597	0.137	1.889
$\tilde{R}_1$	0.091	0.190	4.681	-0.658	0.123	1.716
$\tilde{R}_2$	0.097	0.181	4.902	-0.662	0.137	1.904
$\tilde{R}_3$	0.085	0.189	3.768	-0.329	0.114	1.604
$\tilde{R}_4$	0.078	0.171	3.508	-0.334	0.113	1.618
$\tilde{R}_5$, Green portfolio	0.096	0.175	3.418	-0.311	0.140	1.945
$\tilde{\tilde{R}}_b$, Brown portfolio	0.094	0.187	4.384	-0.612	0.120	1.783
FTSE4Good Europe Index	0.038	0.143	4.016	-0.468	0.056	0.947
STOXX Europe TMI	0.045	0.187	4.559	-0.652	0.053	0.858

Figure 5: Monthly cumulative returns of the green and brown portfolios, FTSE4Good EU Index and STOXX EU TMI.



Considering well-known models in the financial literature, we investigate the drivers of excess returns for the portfolios. Table 2 reports the estimated factor loadings for the five-factor Fama-French model (Fama and French, 2015), the Cahart model (i.e., the four-factor model, see Carhart, 1997), the three-factor Fama-French model (Fama and French, 1993), and the CAPM (Sharpe, 1964; Black, 1972; Lintner, 1965). Results are reported for the various portfolios. The estimated factor loading for the market factor $\hat{b}_m$ is positive and significant across all models and portfolios. However, for portfolios characterized by a darker shade of green, the exposition to the market factor is lower compared to other portfolios. The difference in cumulative returns between the green and the brown portfolios can also be explained by the different factor loadings of these two portfolios on the other factors. In particular, the exposition with respect to the size factor, $\hat{b}_{smb}$, enters with opposite signs for green and brown portfolios.

Table 2: Estimation results based on portfolios. The table reports estimated results for the linear factor model in Equation (2). The table gathers results for several portfolios and linear models. * Statistical significance at the 5% level.

Portfolio	$\tilde{R}$	$\tilde{R}_1$	$\tilde{R}_2$	$\tilde{R}_3$	$\tilde{R}_4$	Green portfolio	$\tilde{\tilde{R}}$	Brown portfolio
Five-factor Fama-French model								
$\hat{a}$	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.002
$\hat{b}_m$	0.976*	1.04*	0.986*	1.037*	0.947*	0.949*	1.035*	1.035*
$\hat{b}_{smb}$	-0.155*	-0.048	-0.034	-0.188*	-0.213*	-0.155*	0.132*	0.309*
$\hat{b}_{hml}$	-0.118*	-0.257*	-0.124	-0.24	-0.296*	-0.085	-0.184*	-0.187*
$\hat{b}_{rmw}$	0.265*	0.114	0.229	0.364*	0.01	0.277*	0.277*	0.105
$\hat{b}_{cma}$	0.153*	0.136	0.156	0.14	0.337*	0.236*	0.046	0.088
Adjusted R-squared	0.978	0.917	0.932	0.889	0.912	0.917	0.963	0.940
Four-factor Carhart model								
$\hat{a}$	0.001	0.001	0.002	0.000	0.000	0.003*	0.001	0.003*
$\hat{b}_m$	0.971*	1.029*	0.976*	1.036*	0.924*	0.912*	1.041*	1.015*
$\hat{b}_{smb}$	-0.201*	-0.079	-0.074	-0.241*	-0.260*	-0.230*	0.097	0.270*
$\hat{b}_{hml}$	-0.157*	-0.243*	-0.147*	-0.334*	-0.096	-0.177*	-0.261*	-0.213*
$\hat{b}_{mom}$	0.086*	0.045	0.069	0.092	0.150*	-0.034	0.073*	-0.028
Adjusted R-squared	0.978	0.917	0.931	0.889	0.917	0.913	0.962	0.940
Three-factor Fama-French model								
$\hat{a}$	0.002*	0.001	0.002*	0.001	0.001	0.003*	0.001	0.002*
$\hat{b}_m$	0.957*	1.021*	0.965*	1.020*	0.899*	0.917*	1.029*	1.020*
$\hat{b}_{smb}$	-0.208*	-0.082	-0.08	-0.248*	-0.272*	-0.227*	0.091	0.272*
$\hat{b}_{hml}$	-0.212*	-0.271*	-0.191*	-0.393*	-0.191*	-0.155*	-0.308*	-0.195*
Adjusted R-squared	0.975	0.917	0.930	0.887	0.908	0.914	0.962	0.938
CAPM								
$\hat{a}$	0.002*	0.002	0.003*	0.002	0.001	0.003*	0.002	0.003*
$\hat{b}_m$	0.912*	0.962*	0.924*	0.936*	0.859*	0.885*	0.960*	0.974*
Adjusted R-squared	0.909	0.926	0.863	0.894	0.905	0.950	0.926	0.926

Considering the Carhart model, the momentum factor is not significant, except for the green portfolio $\tilde{R}_5$ and the fourth-quintile green portfolio (i.e., $\tilde{R}_4$). As for the value factor, $\hat{b}_{hml}$, the estimated loading is always negative and significant when using the three-factor model. Focusing on the green portfolio, we observe a significantly positive intercept for the CAPM, the three- and the four-factor models. The five-factor model is able to best explain returns on the green portfolio, with an associated adjusted R-squared of 91.7%.

We define the green factor as the difference between the monthly returns of the green portfolio and the brown portfolio:

$$r_{g,t} = \tilde{R}_{5,t} - \tilde{\tilde{\tilde{R}}}_{b,t}. \tag{7}$$

Table 3 reports the descriptive statistics of the Fama-French observable factors, the momentum and the green factor, including their cross-correlations. The green factor is comparable in terms of mean, standard deviation, kurtosis and skewness to the other observable factors. The green factor is however generally not highly correlated with the other factors.

Table 3: Descriptive statistics of observable factors. The table reports yearly mean in percentage and standard deviation, kurtosis and skewness, of Fama-French factors, momentum and green factor. The table reports also the correlation matrix among the observable factors.

Factor	Mean	Std	Kurtosis	Skewness	r_m	r_{smb}	r_{hml}	r_{rmw}	r_{cma}	r_{mom}	r_{gf}
r_m	6.035	0.189	4.690	-0.642	1						
r_{smb}	2.089	0.063	3.052	-0.129	-0.025	1					
r_{hml}	-1.378	0.079	3.582	0.519	0.533	-0.010	1				
r_{rmw}	4.655	0.052	2.984	-0.241	-0.398	-0.110	-0.784	1			
r_{cma}	0.929	0.048	4.572	0.623	-0.257	-0.233	0.302	-0.238	1		
r_{mom}	9.398	0.131	19.610	-2.546	-0.439	-0.027	-0.506	0.410	0.165	1	
r_{gf}	0.288	0.066	3.382	0.009	-0.025	-0.296	0.032	0.001	0.317	-0.092	1

5.2 Asset Pricing Analysis on European assets

In this section, we investigate if the green factor defined in Equation (7) affects the cross-section of stock returns and the 25 European Fama-French portfolios. In other words, we test whether investors accept lower compensation for holding environmentally friendly stocks by searching for a negative risk premium, i.e. a greenium.

We consider the linear factor model in Equation (2), where the vector of observable factors f_t contains the following two elements: the excess returns on the European value-weighted market portfolio r_m, and the return of the green factor r_g. Thus, the excess returns $R_{i,t}$ follow the two-factor model

$$R_{i,t} = a_i + b_{m,i} r_{m,t} + b_{g,i} r_{g,t} + \varepsilon_{i,t}. \tag{8}$$

Based on Equation (8), we get the following asset pricing restriction:

$$a_{i,t} = b_{m,i}\nu_m + b_{g,i}\nu_g, \tag{9}$$

and the risk premia of the market and the green factors are defined, respectively, as follows:

$$\lambda_m = E[r_{m,t}] + \nu_m, \text{ and } \lambda_g = E[r_{g,t}] + \nu_g. \tag{10}$$

In order to estimate the risk premia for the observable factors using individual stocks, we follow the estimation procedure proposed in GOS.[10] This procedure allows to deal with unbalanced panels, which is an issue with individual stocks as opposed to portfolios, and involves the following steps. First, we estimate the linear factor model by using the Ordinary Least Square (OLS) estimator. Second, we use the fitted residuals to test whether the model is correctly specified. In particular, we compute the diagnostic criterion proposed in Gagliardini et al. (2019), which checks whether the error terms share at least one unobserved common factor. The criterion does not detect any common factor for the residuals, hence, we conclude for the validity of the factor structure in Equation (8).[11] Third, we compute the cross-sectional estimator of the vector $\nu = (\nu_m, \nu_{gf})'$ by regressing the $\hat{b}_i$ on the $\hat{a}_i$, using the Weighted Least Square (WLS) approach. Finally, the risk premia estimators are

$$\hat{\lambda}_m = \bar{r}_m + \hat{\nu}_m, \text{ and } \hat{\lambda}_g = \bar{r}_g + \hat{\nu}_g, \tag{11}$$

where $\bar{r}_m$ and $\bar{r}_g$ are the sample moments of $E[r_{m,t}]$ and $E[r_{g,t}]$, respectively.

In a second exercise, we estimate the risk premia based on the 25 European Fama-French portfolios. We use the same estimation procedure as described above. Notice, however, that when applied to portfolios this procedure is equivalent to the two-pass cross-sectional regression (see Fama and MacBeth, 1973; Lintner, 1965).

Table 4 shows the estimated market risk premium and the Greenium based on individual stocks and portfolios. The estimated risk premium for the market factor is positive across the two universes of assets. However, it is significant only for the individual stocks at 10%. The estimated Greenium is negative for both individual stocks and portfolios and significant at 5% and 10%, respectively. The negative coefficients indicate that investors accept lower compensation, *ceteris paribus*, to hold assets that correlate positively with the green factor, i.e. greener assets.

Table 4: The table reports the estimated annualized market risk premium and the Greenium. The confidence intervals are reported at the 90% probability level. * and ** denote significance at 10% and 5%, respectively. The results are reported for the European individual stocks and for the 25 European Fama-French portfolios (25 FF).

	Market risk premium			Greenium	
	Stocks	25 FF		Stocks	25 FF
λ_{mkt}	11.24*	5.95	λ_g	-5.82**	-8.17*
	(1.24, 21.24)	(-4.07, 15.96)		(-9.08, -2.55)	(-15.97, -0.38)

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[10] See GOS, Section 3.2 for details on the estimation approach.

[11] The difference between the largest eigenvalue of the empirical cross-sectional covariance matrix of the residuals $\hat{\varepsilon}_{i,t}$ and the penalization term, as defined in Gagliardini et al. (2019), is equal to -0.76.

6 Carbon stress test on actual holdings

Based on the estimates derived in the previous section, we carry out a carbon stress test on the actual equity holdings of the various institutional sectors, at the global level, and of European SIFIs, in particular. The aim of a carbon stress test is to measure the exposure of financial institutions to climate risk, in a scenario where more stringent sustainability-oriented policies are progressively implemented, with increasing pressure on comparatively more carbon-intensive firms and sectors. In such a scenario, the expected returns on greener stocks increase, as more sustainable firms are able to distribute higher dividends, while the price of brown stocks drops for the same reason. In other words, the expected return of more sustainable firms conditional to the implementation of sustainability policies increases. Formally, this implies that the return on the green factor in Equation (7), which is positively correlated with returns on greener stocks, increases.

We test the resilience of the financial sector to climate risk by borrowing equity exposure data and the sustainability classification of economic sectors from Battiston et al. (2017). Following the indication provided by the authors as supplementary information in Table 3, which defines climate-policy-relevant sectors, we group individual stocks (see Section 5) according to their associated NACE code. In particular, we classify stocks in the following six economic sectors: fossil fuels and energy intensive activities, housing, utilities, transport, finance and other.[12]

Table 1 in Battiston et al. (2017) provides aggregate holdings into these climate-policy-relevant sectors, as of 2015, for the following institutional sectors: Individuals, Governments (GOV), Non-Financial Companies (NFCs), Other Credit Institutions (OCIs), Other Financial Services (OFSs), as well as the institutional financial sectors as defined in the ESA classification, i.e. Banks, Investment Funds (IFs), and Insurance and Pension Funds (IPFs). Battiston et al. (2017) also classify equity holdings of individual financial institutions by climate-policy-relevant sectors, obtaining the share of their portfolio invested into each of these sectors. Based on their data, we focus on European SIFIs, as identified by the Financial Stability Board.

The equity portfolio of an institutional sector or an individual institution j at time t is defined as follows:

$$R_{j,t} = \sum_{\kappa=1}^{6} \omega_{\kappa} R_{\kappa,t}, \tag{12}$$

where ω_{κ} corresponds to the equity exposure to the climate-policy-relevant sector κ and $R_{\kappa,t}$ is the monthly average value weighted portfolio return of sector κ.

For each institutional sectors and individual bank j, we compute the marginal expected shortfall (MES) introduced by Acharya et al. (2010). The MES is defined as the expected equity loss conditional on a particular factor return taking a loss greater than Γ. However, in this particular context we want to estimate the expected equity loss conditional on the green factor return defined in Equation (7) realizing a gain greater than Γ, i.e. a scenario where greener stocks outperform brown stocks by more than a particular threshold. Hence, we can write the MES

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[12] Considering the limited cross sectional dimension of our sample compared to Battiston et al. (2017), we combine fossil fuels and energy intensive activities into one sector. The list of firms in our sample that belongs to these sectors is provided in the annex.

as follows:

$$MES_{j,t} = -E[R_{j,t}| - r_{g,t} < -\Gamma], \quad (13)$$

$$= -E[R_{j,t}|r_{g,t} > \Gamma]. \quad (14)$$

We compute the MES considering the following three scenarios, which are defined in terms of portfolio allocation for both institutional sectors and European SIFIs:

- *Baseline Scenario*: the portfolio allocation of institutional sectors and European SIFIs is defined as in Equation (12) and reflects the actual allocation as in Battiston et al. (2017). The portfolio share invested in each of the stocks included in on our sample is derived accordingly.
- *Scenario 1*: the portfolio allocation of institutional sectors and European SIFIs is defined as $R_{j,t} = \frac{1}{2}\omega_{j,1}R_{1,t} + \frac{1}{2}\omega_{j,1}R_t^{+} + \sum_{\kappa=2}^{6}\omega_{j,\kappa}R_{\kappa,t}$, where the exposure to the fossil fuel and energy intensive sector is reduced by 50% compared to the baseline and investments are reallocated to greener stocks. These are defined as the stocks with a positive exposition to the green factor, that is those with $b_{g,i} > 0$ in Equation (8).
- *Scenario 2*: the portfolio allocation of institutional sectors and European SIFIs is defined as $R_{j,t} = \sum_{\kappa=1}^{6}\omega_{j,\kappa}R_{\kappa,t}^{+}$, i.e. only green stocks, as defined above, are included in the portfolio.

In a first exercise, in all three scenarios, the $MES_{j,t}$ is computed w.r.t. the event $r_{g,t} > q_{0.7}$, where $q_{0.7}$ indicates the 70^{th} percentile of the distribution of the green factor. This means that we calculate the MES considering a relatively large interval, while normally it would be computed considering the very tail of the distribution. To design a realistic carbon stress test, we do not focus on extreme states of the world where greener stocks dramatically outperform brown stocks. Instead, we aim at providing a credible measure of the exposure to climate risk of institutional sectors as well as individual banks. Indeed, the assumption on which our MES estimate is based is consistent with the evidence provided in Section 5, where we show that the green portfolio has indeed outperformed the brown portfolio over the last 12 years, albeit not hugely.

Table 5 reports MES results for the institutional sectors at the global level and the European SIFIs in Panel A and Panel B, respectively. The MES is expressed both as percentage loss and in billions of US dollars. The average MES in the baseline scenario, i.e. given the actual portfolio allocation based on 2015 data, is around -0.5%, with very limited variation across institutional sectors and institutions, indicating that no one would be immune. This percentage loss corresponds to USD 138 bn at the global level, and to slightly more than USD 4 bn focussing on European SIFIs alone. These figures are admittedly not breathtaking, and one might argue that losses of this magnitude would be unlike to trigger a financial crisis. However, based on the very mild severity of the underlying assumptions, on the historical outperformance of greener assets versus brown ones, and on the expectation that sustainability considerations will increasingly be at the core of policy action, these results can be interpreted as a lower bound for expected losses. Any more challenging scenario, e.g. due to an acceleration in the implementation of climate-related policies, will lead to larger losses in the absence of a suitable portfolio reallocation.

Table 5 also shows what would happen should a portfolio reallocation take place. The figures obtained under Scenario 1 indicate that halving the exposure to carbon-intensive sectors would reduce the MES to slightly less than USD 100 bn at the global level and to around USD 3 bn for European SIFIs, which correspond to a decrease of around 30%. Under Scenario 2, characterized by a radical portfolio reallocation, no institutional sector would record losses, as well as almost all European SIFIs.

Table 5: The table reports the MES in percentage terms and in billions of dollars, for the three scenarios, for global institutional sectors and European SIFIs in Panel A and Panel B, respectively.

Panel A

	MES (%)			**MES (Bn $)**		
Institutional sectors	**Baseline**	**Scenario 1**	**Scenario 2**	**Baseline**	**Scenario 1**	**Scenario 2**
OCIs	-0.57%	-0.40%	0.09%	-2.96	-2.07	0.46
GOV	-0.53%	-0.37%	0.12%	-3.06	-2.13	0.67
Individuals	-0.49%	-0.35%	0.18%	-12.82	-9.08	4.59
Banks	-0.53%	-0.39%	0.09%	-14.43	-10.61	2.58
IPFs	-0.51%	-0.36%	0.16%	-16.43	-11.68	5.07
OFSs	-0.52%	-0.37%	0.15%	-17.95	-12.72	5.18
NFCs	-0.52%	-0.35%	0.18%	-24.27	-16.53	8.52
Ifs	-0.51%	-0.36%	0.17%	-46.47	-32.37	15.32
Average and Total	**-0.51%**	**-0.36%**	**0.16%**	**-138.38**	**-97.19**	**42.39**

Panel B

	MES (%)			**MES (Bn $)**		
European SIFIs	**Baseline**	**Scenario 1**	**Scenario 2**	**Baseline**	**Scenario 1**	**Scenario 2**
DEUTSCHE BANK	-0.53%	-0.37%	0.14%	-0.85	-0.60	0.22
BPCE	-0.55%	-0.42%	0.04%	-0.81	-0.61	0.06
BNP PARIBAS	-0.53%	-0.39%	0.10%	-0.36	-0.26	0.06
UNICREDIT	-0.53%	-0.38%	0.11%	-0.16	-0.11	0.03
BARCLAYS	-0.53%	-0.38%	0.11%	-0.20	-0.14	0.04
CREDIT SUISSE	-0.52%	-0.36%	0.16%	-0.48	-0.33	0.14
BANCO SANTANDER	-0.58%	-0.58%	-0.36%	-0.05	-0.05	-0.03
UBS	-0.53%	-0.36%	0.17%	-0.96	-0.65	0.31
ING BANK	-0.70%	-0.63%	-0.42%	-0.01	-0.01	-0.01
SOCIETE GENERALE	-0.57%	-0.42%	0.04%	-0.28	-0.20	0.02
Average and Total	**-0.57%**	**-0.42%**	**0.04%**	**-4.14**	**-2.97**	**0.86**

In a second application, we investigate what would happen to the financial system under a more extreme, but still plausible, scenario. To run this carbon stress test, we redo the same exercise by computing the $MES_{j,t}$ w.r.t the event $r_g > q_{0.9}$, i.e. considering realizations that are larger than the 90% percentile of the distribution. Table 6 reports the resulting MES in term of percentage and absolute losses for Institutional sectors and European SIFIs, respectively. In this stressed scenario, losses reach one trillion at global level and 31 billions for European SIFIs. In this case, even with a drastic portfolio reallocation, losses would still be recorded. However, they would still decrease by up to around 30% both globally and for European SIFIs.

Table 6: The table reports the MES in percentage terms and in billions of dollars, for the three scenarios, for global institutional sectors and European SIFIs in Panel A and Panel B, respectively, in a more severely stressed scenario.

Panel A

	MES (%)			**MES (Bn $)**		
Institutional sectors	**Baseline**	**Scenario 1**	**Scenario 2**	**Baseline**	**Scenario 1**	**Scenario 2**
OCIs	-4.11%	-3.73%	-2.86%	-21.29	-19.30	-14.79
Governments	-3.96%	-3.60%	-2.70%	-22.92	-20.84	-15.61
Individuals	-3.94%	-3.61%	-2.56%	-102.42	-93.96	-66.70
Banks	-4.01%	-3.69%	-2.77%	-109.50	-100.89	-75.78
IPFs	-3.95%	-3.62%	-2.62%	-128.26	-117.54	-84.90
OFSs	-3.97%	-3.64%	-2.64%	-138.04	-126.26	-91.63
Non-Financial Companies	-3.98%	-3.61%	-2.58%	-186.44	-168.97	-120.88
Investment Funds	-3.95%	-3.60%	-2.59%	-359.05	-327.25	-235.13
Average and Total	**-3.97%**	**-3.62%**	**-2.62%**	**-1067.92**	**-975.00**	**-705.43**

Panel B

	MES (%)			**MES (Bn $)**		
European SIFIs	**Baseline**	**Scenario 1**	**Scenario 2**	**Baseline**	**Scenario 1**	**Scenario 2**
DEUTSCHE BANK AG	-3.98%	-3.63%	-2.67%	-6.43	-5.86	-4.31
BPCE SA	-4.08%	-3.78%	-2.92%	-5.97	-5.53	-4.27
BNP PARIBAS	-4.07%	-3.74%	-2.83%	-2.73	-2.51	-1.91
UNICREDIT SPA	-4.00%	-3.68%	-2.75%	-1.18	-1.09	-0.81
BARCLAYS PLC	-4.01%	-3.68%	-2.76%	-1.52	-1.39	-1.04
CREDIT SUISSE GROUP AG	-3.97%	-3.61%	-2.63%	-3.64	-3.31	-2.41
BANCO SANTANDER SA	-4.24%	-4.23%	-3.82%	-0.34	-0.34	-0.31
UBS GROUP AG	-3.98%	-3.60%	-2.61%	-7.24	-6.55	-4.75
ING BANK NV	-4.53%	-4.38%	-4.13%	-0.09	-0.08	-0.08
SOCIETE GENERALE GESTION	-4.10%	-3.75%	-2.93%	-2.01	-1.84	-1.44
Average and Total	**-4.02%**	**-3.68%**	**-2.75%**	**-31.15**	**-28.51**	**-21.32**

7 Conclusions

Companies which invest in improving their sustainability performance, including environmental, also see an improvement in their economic and financial performance. This happens because by doing so, they lower their exposure to environmental, and in particular climate, risk. However, so far no consistent evidence was available in the literature based on stock returns, and an estimate of the risk premium associated to climate risk, which we call Greenium, was the Holy Grail of asset pricing research in relation to sustainable finance.

Based on European data, we provide evidence of the existence of a pricing factor linked to climate risk and find that the Greenium, i.e. the associated risk premium, is negative and significant. We obtain this result because we take green seriously, unlike studies based on publicly traded funds or indices, which often market themselves as greener than they actually are. To control for greenwhashing, we construct an index of greenness at the individual company level, which we use to build portfolios characterized by various shades of green. In terms of returns on green investment, we calculate that 100 Euro invested in 2006 in a green portfolio would have yield 120 Euro today, compared to 112 Euro for a brown portfolio. These two portfolios are used to define the green factor.

Finally, we use our model to price the equity holdings of institutional sectors at the global level and of individual European SIFIs. We find that that their current allocation in terms of green vs brown sectors exposes them to non-negligible losses in a perfectly plausible scenario where green assets outperform brown assets, but not dramatically. In a more extreme scenario, losses would amount to \$1 tn globally, and more than \$30 bn for European SIFIs. We calculate that halving their exposure to carbon-intensive sectors would decrease their losses by around 30%. Based on our results, and considering that we only focus on equity exposures, we argue in favor of introducing carbon stress tests for systemic financial institutions. Indeed, the consequences of a mispricing of environmental risks would be widespread already in a plain vanilla scenario, and could become serious for any more severe scenario.

References

Acharya, V., Pederson, L., Philippon, T., and Richardson, M. (2010). Measuring systemic risk. *Technical report, Department of Finance, NYU.*

Ambec, S. and Lanoie, P. (2008). Does it pay to be green? A systematic overview. *Academy of Management Perspectives*, 22:45–62.

Andersson, M., Bolton, P., and Samama, F. (2016). Hedging climate risk. *Financial Analysts Journal*, 72(3):13–32.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., and Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7(4):283.

Battiston, S. and Monasterolo, I. (2018). A carbon risk assessment of central banks' portfolios under 2° C aligned climate scenarios. *Working Paper.*

Black, F. (1972). Capital market equilibrium with restricted borrowing. *The Journal of Business*, 45(3):444–454.

Bolton, P. and Kacperczyk, M. (2019). Do investors care about carbon risk? *Working Paper.*

Bragdon, J. H. and Marlin, J. (1972). Is pollution profitable? *Risk management*, 19(4):9–18.

Campiglio, E., Godin, A., and Kemp-Benedict, E. (2017). Networks of stranded assets: A case for a balance sheet approach.

Carhart, M. (1997). On persistence of mutual fund performance. *Journal of Finance*, 52(1):57–82.

Carney, M. (2015). Breaking the tragedy of the horizon—climate change and financial stability. *Speech given at Lloyd's of London, September*, 29.

Chamberlain, G. and Rothschild, M. (1983). Arbitrage, factor structure, and mean-variance analysis on large asset markets. *Econometrica*, 51(5):1281–1304.

Choi, D., Gao, Z., and Jiang, W. (2018). Attention to global warming. *Working Paper.* Available at SSRN: https://ssrn.com/abstract=3180045.

Daniel, K. D., Litterman, R. B., and Wagner, G. (2016). Applying asset pricing theory to calibrate the price of climate risk. Technical report, National Bureau of Economic Research.

Derwall, J., Guenster, N., Bauer, R., and Koedijk, K. (2005). The eco-efficiency premium puzzle. *Financial Analysts Journal*, 61(2):51–63.

Donadelli, M., Jüppner, M., Riedel, M., and Schlag, C. (2017). Temperature shocks and welfare costs. *Journal of Economic Dynamics and Control*, 82:331–355.

Engle, R. F., Giglio, S., Lee, H., Kelly, B. T., and Stroebel, J. (forthcoming, 2019). Hedging climate change news. *Revie of Financial studies*.

Fama, E. F. and French, K. R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics*, 33(1):3–56.

Fama, E. F. and French, K. R. (2008). Dissecting anomalies. *Journal of Finance*, 63(4):1653–1678.

Fama, E. F. and French, K. R. (2015). A five-factor asset pricing model. *Journal of Financial Economics*, 116(1):1–22.

Fama, E. F. and MacBeth, J. D. (1973). Risk, return, and equilibrium: Empirical tests. *Journal of Political Economy*, 81(3):607–36.

Gagliardini, P., Ossola, E., and Scaillet, O. (2016). Time-varying risk premium in large cross-sectional equity datasets. *Econometrica*, 84(3):985–1046.

Gagliardini, P., Ossola, E., and Scaillet, O. (forthcoming, 2019). A diagnostic criterion for approximate factor structure. *Journal of Econometrics*.

Goergen, M., Jacob, A., Nerlinger, M., Riordan, R., Rohleder, M., and Wilkens, M. (2019). Carbon risk. Technical report, University of Augsburg, Queen's University.

Gore, A. (1993). *Earth in the Balance: Ecology and the Human Spirit*. New York: Penguin.

Gros, D., Lane, P., Langfield, S., Matikainen, S., Pagano, M., Schoenmaker, D., and Suarez, J. (2016). Too late, too sudden: Transition to a low-carbon economy and systemic risk. Technical report, European Systemic Risk Board.

Hartzmark, S. M. and Sussman, A. B. (2018). Do investors value sustainability? A natural experiment examining ranking and fund flows. *European Corporate Governance Institute (ECGI)*, (Finance Working Paper No. 565/2018).

Hoepner, A. G. F., Oikonomou, I., Sautner, Z., Starks, L. T., and Zhou, X. (2018). ESG shareholder engagement and downside risk. *AFA 2018 paper*.

Hong, H., Li, F. W., and Xu, J. (2019). Climate risks and market efficiency. *Journal of Econometrics*, 208(1):265–281.

Kumar, N., Shashwat, A., and Wermers, R. (2018). Do fund managers misestimate climatic disaster risk? *Working Paper*.

Lewellen, J., Nagel, S., and Shanken, J. (2010). A skeptical appraisal of asset-pricing tests. *Journal of Financial Economics*, 96(2):175–194.

Lintner, J. (1965). The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets. *Review of Economics and Statistics*, 47(1):13–37.

Margolis, J. D., Elfenbein, H. A., and Walsh, J. P. (2009). Does it pay to be good... and does it matter? A meta-analysis of the relationship between corporate social and financial performance. *Working paper.*

Monasterolo, I. and De Angelis, L. (2019). Blind to carbon risk? an analysis of stock market's reaction to the Paris Agreement. *Working Paper University of Bologna.*

Monasterolo, I., Zheng, J. I., and Battiston, S. (2018). Climate transition risk and development finance: A carbon risk assessment of china's overseas energy portfolios. *China & World Economy*, 26(6):116–142.

Pindyck, R. S. (2013). Climate change policy: what do the models tell us? *Journal of Economic Literature*, 51(3):860–72.

Porter, M. (1991). America's green strategy. *Scientific American*, 264(4):168.

Porter, M. and van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship, 9(4), 97–118. *Journal of Economic Perspective.*

Renneboog, L., ter Horst, J. R., and Zhang, C. (2007). Socially responsible investments: Methodology, risk exposure and performance. *TILEC Discussion Paper No. 2007-013.*

Seitz, J. (2010). Nachhaltige investments: eine empirisch-vergleichende analyse der performance ethisch-nachhaltiger investmentfonds in europa. *Hamburg: Diplomica Verlag.*

Sharpe, W. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk. *Journal of Finance*, 19(3):425–442.

Sharpe, W. (1994). The Sharpe ratio. *Journal of portfolio management*, 21(1):49–58.

Statman, M. (2000). Socially responsible mutual funds (corrected). *Financial Analysts Journal*, 56(3):30–39.

Trinks, A., Scholtens, B., Mulder, M., and Dam, L. (2018). Fossil fuel divestment and portfolio performance. *Ecological Economics*, 146:740–748.

Annex

Table 7: List of firms, in our sample, whose main business belongs to the fossil fuel and energy intensive activities. In term of Nace sectors, they are all classified as Mining and Quarrying. In term of Nace 4 digit classification, they are ”Mining of chemical and fertilizer minerals, code 08.91.

N	Company Name	Country of Domicile	N	Company Name	Country of Domicile
1	BHP Billiton PLC	Australia	21	Lubelski Wegiel Bogdanka SA	Poland
2	Schoeller-Bleckmann Oilfield Equipment A	Austria	22	Jastrzebska Spolka Weglowa SA	Poland
3	Antofagasta PLC	Chile	23	Polymetal International PLC	Russia
4	Saipem SpA	Italy	24	Lundin Petroleum AB	Sweden
5	Randgold Resources Ltd	Jersey	25	Granges AB	Sweden
6	Centamin PLC	Jersey	26	Glencore PLC	Switzerland
7	Fresnillo PLC	Mexico	27	Borr Drilling Ltd	U.A.E
8	SBM Offshore NV	Netherlands	28	Shelf Drilling Ltd	U.A.E
9	Norsk Hydro ASA	Norway	29	TechnipFMC PLC	UK
10	Akastor ASA	Norway	30	Anglo American PLC	UK
11	Bonheur ASA	Norway	31	Tullow Oil PLC	UK
12	DNO ASA	Norway	32	Petrofac Ltd	UK
13	Aker BP ASA	Norway	33	Rio Tinto PLC	UK
14	Norwegian Energy Co ASA	Norway	34	Subsea 7 SA	UK
15	Aker Solutions ASA	Norway	35	Sirius Minerals PLC	UK
16	Odfjell Drilling Ltd	Norway	36	Hunting PLC	UK
17	Grupa Kety SA	Poland	37	Cairn Energy PLC	UK
18	KGHM Polska Miedz SA	Poland	38	John Wood Group PLC	UK
19	Stalprodukt SA	Poland	39	Genel Energy Plc	UK
20	Alumetal SA	Poland	40	Soco International PLC	UK
-	-	-	41	Ophir Energy PLC	UK

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