A Scientific Beta Publication

Scientific Beta
An SGX and EDHEC Venture

Green Dilution: How ESG Scores Conflict with Climate Investing

June 2023

Table of Contents

The authors can be contacted at contact@scientificbeta.com.

Abstract

In response to surging investor demand to meet ESG (environmental, social and governance) and climate objectives, many index providers are constructing indices that combine ESG and climate scores in portfolio construction. Faced with this marketing of "more and more" in ESG investing, an important question for investors is to examine the conflict that could arise when adding ESG objectives to carbon reduction objectives in equity portfolios. We quantify the loss of greenness (i.e., increase in carbon intensity) that investors face when weighting stocks by combinations of ESG scores and carbon intensity. Using 25 different ESG scores from three major providers in a global equity universe, we find that the carbon intensity reduction of green portfolios can be effectively cancelled out by adding ESG objectives. This green dilution occurs because ESG ratings have little to no relation to carbon intensity, even when considering only the environmental pillar of these ratings. We show that investors can avoid green dilution by separating the two objectives, i.e., first applying ESG exclusions and then weighting stocks to minimise carbon intensity. Our finding that pursuing multiple ESG and climate objectives without the necessary precautions leads to green dilution is perhaps not surprising. Financial innovation often comes up against unintended consequences. ESG investing is no exception to this phenomenon.

About the Authors

Noël Amenc, is an Associate Professor of Finance at EDHEC Business School, Director of Scientific Infra & Private Assets, and Senior Advisor to Scientific Beta, of which he was the founding CEO. Within EDHEC Business School, he is also Affiliate Member of the EDHEC Risk Climate Impact Institute. Prior to joining EDHEC Business School as founding director of EDHEC-Risk Institute, he was the Director of Research of Misys Asset Management Systems. He has published extensively in finance journals and contributed to four books on quantitative equity management, portfolio management, and alternative investments. He is a member of the editorial board of the *Journal of Portfolio Management*, associate editor of the *Journal of Alternative Investments*, and member of the advisory board of the *Journal of Index Investing*. He is also a member of the Finance Research Council of the Monetary Authority of Singapore. He was formerly a member of the Consultative Working Group of the European Securities and Markets Authority (ESMA) Financial Innovation Standing Committee and of the Scientific Advisory Council of the AMF (French financial regulatory authority). He holds graduate degrees in economics, finance and management and a PhD in finance.

Felix Goltz, PhD, is Research Director at Scientific Beta. He carries out research in empirical finance and asset allocation, with a focus on alternative investments and indexing strategies. His work has appeared in various international academic and practitioner journals and handbooks. He obtained a PhD in finance from the University of Nice Sophia-Antipolis after studying economics and business administration at the University of Bayreuth and EDHEC Business School.

Antoine Naly, is a Senior Quantitative Researcher at Scientific Beta and a member of the EDHEC Scientific Beta research chair. His research focuses on the interactions between equity markets, ESG, and macroeconomic variables. He holds a Master's degree in Financial Economics from HEC Montréal, and previously studied finance and macroeconomics at Lyon 3 University and the University of British Columbia. Prior to joining Scientific Beta, he successively worked as an investment analyst in advisory services at Mercer, as a quantitative macro analyst in global macro research at PGM Global, and as a Macro ESG strategist at Sustainable Market Strategies. He is also a CFA Charterholder.

1. Executive Summary

1. Executive Summary

The successive growth of ESG and climate investing has led practitioners to promote strategies that aim to fulfil both higher ESG scores and lower carbon emissions, without ever considering the potential trade-off between these two dimensions.

We quantify this very trade-off by measuring the carbon intensity increase investors face when they add ESG score objectives to a low carbon intensity objective in global equity portfolios. We account for heterogeneity in ESG preferences by relying on 25 ESG theme scores from three major ESG rating providers, and building portfolios based on numerous combinations of ESG objectives and carbon reduction. By comparing the greenness of portfolios built to have both higher ESG scores and lower carbon intensity to that of portfolios solely built to reduce carbon intensity, we are able to compute the incremental impact of the inclusion of ESG scores on carbon intensity reduction, which we call green dilution.

We show green dilution is pervasive, regardless of which ESG scores are targeted as objectives, substantial, with an average of 92% across our portfolios, and robust across several alternative specifications. A 92% green dilution means that 92% of the carbon intensity reduction investors could have reached by solely weighting stocks to minimise carbon intensity is lost when adding ESG scores as a partial weight determinant. Only 8% of the carbon reduction objective survived the inclusion of ESG scores in portfolio weighting schemes.

Adding a single ESG score in portfolio construction, so that stock weights are equally determined by carbon intensity and the ESG score in question, leads to a green dilution of 65% on average. Mixing ESG scores one might expect to be green, scores belonging to the environmental pillar, with carbon intensity also leads to a substantial deterioration in green performance. Mixing scores from the social or governance pillars with carbon intensity routinely results in portfolios than are less green than the cap-weighted index: on average, social and governance scores more than completely reversed the carbon reduction objective.

Green dilution has a simple explanation. The cross-sectional rank correlation[1] between ESG scores and carbon intensity is close to zero. The two objectives are unrelated and are therefore hard for investors to simultaneously achieve. This low correlation explains why one should not mix ESG and carbon scores in portfolio weighting schemes. A more sensible alternative is to separate the two objectives, by first screening out stocks with low ESG scores, and then weighting the remaining stocks by the investor's key objective, carbon intensity in our case. Since both dimensions are unrelated, screening out stocks by ESG scores does not affect the carbon intensity distribution of the stock universe. ESG exclusions thus result in a neutral impact on portfolio carbon intensity, with a green dilution close to zero.

Overall, we provide clear evidence against the quantitative mixing of ESG and carbon scores in equity portfolio weighting schemes, which comes at great carbon cost for green investors. Conversely, we provide evidence in favour of the exclusionary approach to ESG objectives, to best accommodate multiple non-financial and unrelated objectives.

1 - The cross-sectional absolute correlation is even lower due to outliers.

2. Introduction

2. Introduction

ESG and climate investing have been strong growth areas in investment management in recent years[2], as more and more investors want to include such information in their investment process. To answer this demand, index providers have been quick to build strategies combining both ESG and climate objectives. For instance, they have launched products where stock weights depend on combinations of ESG scores and carbon metrics[3]... It is also common for investments focusing on climate to advertise a strong ESG rating as a proof of good behaviour[4], when the two dimensions could have little relationship in practice. Possible trade-offs between climate and ESG objectives are seldom mentioned by strategy providers.

In this paper we take the perspective of investors who primarily want to reduce the carbon intensity of their portfolio, i.e. "green" investors, while also considering ESG scores. If high ESG scores and low carbon intensity are positively correlated in the cross section of stocks, investors can both be green and fulfil other ESG objectives at the same time. However, if carbon intensity and ESG scores are unrelated, green investors should be aware of the trade-off they face when wanting to be both green and orientated towards ESG criteria.

Indeed, making optimal choices along trade-offs is the essence of portfolio construction. When considering purely financial objectives, investors routinely include competing objectives like expected return, risk and liquidity. Reasonable providers of investment strategies do not promise investors that they can maximise liquidity while minimising volatility and maximising expected returns. Instead, they try to find a good spot along the trade-offs between risk, returns and liquidity. Similarly, when it comes to ESG and climate objectives, portfolios will not be automatically better on several dimensions just by adding more and more criteria. Just like investors face trade-offs among different *financial* objectives, they may face trade-offs between different *nonfinancial* objectives. Building portfolios that attempt to reconcile several objectives thus raises design challenges. Regardless of the chosen approach, combining several quantitative objectives that are not perfectly correlated will result in trade-offs that investors must monitor. The existence of such trade-offs is well documented in the literature on multi-objective portfolio optimisation[5].

To test the compatibility of the climate and ESG dimensions, we build global equity portfolios mixing (higher) ESG scores and (lower) carbon intensities as a determinant of portfolio weights. In contrast to most papers on ESG investing we use granular ESG themes, rather than overall ESG ratings or their main ESG pillar scores (environmental or E, social or S, and governance or G), to account for heterogeneity in the various dimensions of ESG investing. Examples of such themes are human resources and human rights within the social dimension, or resource use and environmental innovation within the environmental dimension. Assessing a large number of possible themes instead of accepting an aggregate score helps us derive results that can be generalised. In addition, we consider such ratings from three main data providers to avoid reliance on a single methodology. We call the portfolios weighted by both ESG scores and carbon intensity ESG and carbon mixing portfolios. We measure their greenness using two metrics. The first one is the Weighted Average Carbon Intensity (WACI), or carbon intensity for short. The second one is the carbon sensitivity of

2 - An October 2022 report from PricewaterhouseCoopers' asset and wealth management unit estimates global ESG Assets Under Management (AUM) went from USD2.2 trillion in 2015 to USD18.4 trillion in 2021, combining AUM estimates from several sources.
3 - See for instance the following indices built using a tilted weighting scheme:
https://research.ftserussell.com/products/downloads/FTSE_ESG_Low_Carbon_Select_Index_Ground_Rules.pdf
https://research.ftserussell.com/products/downloads/FTSE_All_Share_ex_Investment_Trusts_ESG_Climate_Select_Index_Ground_Rules.pdf
4 - For instance, the following climate-focused suite of indices impose the index-weighted average ESG score to be equal or superior to that of the corresponding cap-weighted index:
https://www.spglobal.com/spdji/en/documents/methodologies/methodology-sp-paris-aligned-climate-transition-pact-indices.pdf
5 - See Aouni et al. (2018) for a recent literature review on multi-objective optimisation and Das and Dennis (1997).

2. Introduction

weights, which measures how sensitive stock-level weights are to stock-level carbon intensity, or carbon sensitivity for short. By comparing the greenness of a portfolio solely built to reduce carbon intensity to that of the ESG and carbon mixing portfolios, we can measure green dilution, which is the loss of greenness induced by adding ESG scores to carbon intensity as a determinant of portfolio weights.

We find that mixing ESG ratings with carbon intensity objectives leads to a heavy dilution of portfolio greenness. The average green dilution across various combinations of ESG scores from different providers using the ESG and carbon mixing approach amounts to 92.2%. In other words, averaging ESG scores and carbon intensity in weighting schemes effectively cancels out the carbon reduction objective.

We also test an alternative way of constructing portfolios, where we separate the carbon and ESG objectives, by first excluding stocks with the lowest ESG scores, and weighting the remaining stocks by carbon intensity. We call these portfolios *ESG screening portfolios*[6]. Our results show the seemingly minor choice between including ESG scores in the weighting scheme along with carbon intensity, or as an exclusionary criterion, has a major impact on portfolio greenness. We find that ESG screening allows avoiding green dilution, with measures of dilution close to 0%.

There is a simple explanation why screening avoids dilution. Since ESG scores and carbon intensities are unrelated in our sample, ESG exclusions do not affect the distribution of carbon intensities of the stock universe, allowing investors to minimise carbon intensity almost as well as they would without ESG exclusions. Mixing ESG scores and carbon intensity in weighting schemes, on the other hand, directly dilutes each of the two unrelated metrics. We also note that ESG screening can be implemented without any loss in average ESG score compared to ESG mixing when excluding the bottom 20% to 30% of stocks[7] with the lowest ESG scores in a developed equity universe.

These results are robust to using data across three major ESG rating providers (MSCI, Refinitiv, and Moody's), and two different green dilution metrics. Additionally, we check the robustness of our results using alternative portfolio specifications, controlling for the different numbers of scores across ESG rating providers, testing different weighting schemes (rank based and optimised) and different carbon emission scopes. We confirm our result of strong green dilution for mixing approaches and absence of green dilution for screening approaches across these different specifications.

To our knowledge the trade-off between climate investing and ESG investing, which we assess, has been little explored by the financial literature.

Instead, a main focus of the literature has been on the relationship between ESG characteristics or climate characteristics and expected stock returns. For example, Hong and Kacperczyk (2009) hypothesise that stocks that are shunned due to social norms (sin stocks) should have higher expected returns, and find empirical support for this hypothesis even after controlling for standard

6 - We refer to ESG and carbon mixing portfolios, and ESG screening portfolios taken together as multiple-objectives portfolios, since they aim to fulfil both ESG and climate objectives.
7 - The exact level of ESG exclusions required for the screening portfolios to match the ESG scores of the ESG and carbon mixing approach depends on which ESG themes are considered, see details in Appendix 3.

2. Introduction

equity factors. Pastor, Taylor, and Stambaugh (2021) theoretically show that stocks that fulfil ESG preferences and climate hedging concerns are associated with lower expected returns[8]. Bolton and Kacperczyk (2021) find that absolute carbon emissions are associated with a positive premium in the cross section of US stocks, but that this premium disappears when normalising carbon emissions by revenues[9] (also see Aswani, Raghunandan, and Rajgopal 2023). Literature reviews, such as Gerard (2022), Matos (2020), Liang and Renneboog (2021), and Atz et al. (2022) show that evidence on the relationship between ESG criteria and returns is mixed overall[10].

Another strand of ESG research has studied the relationship between ESG ratings across different providers. This literature has documented divergence in ESG ratings and analysed its consequences for investors from both risk/return and ESG perspectives. For example, Berg, Kölbel, and Rigobon (2022) show there is strong divergence of scores across different providers for similar ESG topics and several studies find that ratings disagreement obscures the relation with returns (Avramov et al., 2021; Lindsey, Pruitt, and Schiller 2021).

This paper instead looks at the relationship between different sustainable investing dimensions: climate and ESG. We assess the relationship between climate criteria and other ESG themes and analyse the resulting trade-offs. We use ESG data at the granular level of particular ESG themes and assess how compatible different themes are with climate objectives[11].

8 - Also see Pedersen, Fitzgibbons, and Pomorski (2021) who derive an ESG-efficient frontier and an ESG-adjusted CAPM.
9 - Other research focused on green portfolios includes Andersson, Bolton, and Samama (2016) who show investors can build equity portfolios with a 50% reduction in carbon intensity with little to no tracking error to European cap-weighted indices and, Ardia et al. (2021) who find excess green returns are conditional on unexpected shifts in climate concern from investors, and Pastor, Taylor, and Stambaugh (2022) who find that concern for climate risk explains the positive returns of a green minus brown factor from 2012 to 2020.
10 - Other articles focus on the source of ESG returns, finding significant exposure to traditional equity factors: Madhavan, Sobczyk, and Ang (2021) show ESG mutual funds have a quality and momentum bias. Chan et al. (2020) show that one can preserve factor exposure in global equities while imposing ESG and carbon intensity constraints. Bruno, Esakia, and Goltz (2021) show that reported ESG outperformance may be driven by exposure to style factors and ESG taste shifts.
11 - Our work is related to Amenc, Goltz, and Liu (2022) who studied both pure climate strategies and strategies that mix climate and ESG objectives. However, this earlier paper does not analyse the implications of mixing these dimensions in detail, does not identify the drivers of differences between pure carbon and mixed strategies, and does not assess more granular data than aggregate ESG ratings.

3. Data

3. Data

We build global developed equity portfolios based on the Scientific Beta developed universe[12], using only two types of weight determinants: carbon intensity and ESG scores, from December 2013 to December 2019. This enables us to build portfolios with annual rebalancing in December and returns running from December 2013 to September 2020. We use Scope 1+2 carbon intensity data from Institutional Shareholder Services (ISS)[13]. To account for ESG ratings disagreement (see Berg, Kölbel, and Rigobon, 2022) we use ESG scores from three different providers, MSCI, Refinitiv, and Moody's. ESG scores have different levels of granularity, which can be roughly summarised in the following levels. There is one overall ESG score by company, which comprises three ESG pillar scores (E, S and G). Each ESG pillar score is a combination of ESG theme scores (one to four theme scores per pillar), which are themselves a combination of various numbers of ESG topic scores[14]. To take heterogeneity in ESG preferences into account, we use theme scores rather than overall ESG scores or ESG pillar scores as portfolio inputs. We refer to these scores as themes, but each rating provider has its own terminology, they are called "themes" in MSCI terminology using the IVA dataset, "categories" in Refinitiv (formerly Asset4) terminology, and "domains" in Moody's (formerly Vigeo Eiris) terminology using the Equitics dataset. Each ESG rating company has different methodologies to assess ESG performance.

We also require high theme score coverage in our developed equity universe to build diversified portfolios. Theme score coverage reaches 75% of stocks on average across all themes and years from 2013 to 2019[15]. To further improve coverage, we fill missing observations using a common-sense procedure with two ingredients:
i) Given the stability of available scores, we interpolate missing scores through time and carry scores over for 1 year when they become missing
ii) Given that each theme is related to a pillar, we extrapolate theme scores from pillar scores when they are missing.

The detailed procedure is available in Appendix 1, while coverage percentages over time before and after expansion for each theme are available in Appendix 2. This procedure enables sufficient coverage for almost all themes to be achieved. We keep nine MSCI themes out of 10, since the theme called "Stakeholder Opposition" belonging to the social pillar had a coverage that is too low to be expanded and could not be used. All 10 Refinitiv themes and all six Moody's themes are retained after coverage expansion. The list of ESG themes we use in portfolio construction is shown in Table 1 below.

Before building any portfolios, we can get a sense of the potential for green dilution by looking at the correlations between carbon intensity and ESG theme scores in the cross section of stocks. If ESG theme scores are perfectly negatively correlated to carbon intensity (stocks with the best ESG theme scores also have the lowest carbon intensity), investors would not face any green dilution as green portfolios would already have high ESG theme scores. If ESG theme scores have less than perfect negative correlation to carbon intensity, we can expect mild dilution, indicating a moderate

12 - The developed universe consists of large- and mid-cap companies located in 23 developed countries including: Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece (before June 2015), Hong Kong, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, South Korea (before June 2015), Spain, Sweden, Switzerland, UK and US. The universe contains a fixed number of 1,470 stocks.
13 - We rely on data provided by Scientific Beta. Scientific Beta uses the ISS raw carbon emissions data and assigns NA values to incorrect or suspect carbon intensities. Stocks with NA carbon intensity values will be excluded from ESG mixing and ESG screening portfolios. Incorrect carbon intensities are defined by negative or null carbon emissions, or negative or null revenues. Suspect carbon intensities are defined by meeting either one of the following three criteria: carbon intensities above or equal to the 97.5th percentile (by geographical region) when revenues are below or equal to the 2.5th percentile, market-capitalisation-to-revenues ratio above or equal to the 97.5th percentile, and market capitalisation over 500 times revenues.
14 - Moody's Equitics scores are technically standalone scores rather than part of pillar scores but since they naturally fall under pillars, we assigned each score to the most relevant ESG pillar (E, S, or G) as shown in Table 1.
15 - Detailed coverage for each ESG theme score over time is shown in Appendix 2.

3. Data

trade-off for investors. If correlations are close to zero (the two dimensions are unrelated) or even positive (high carbon intensity stocks tend to have high ESG theme scores), we should expect a stronger trade-off or even an incompatibility between carbon reduction and ESG theme objectives. Table 2 shows the average rank correlations between ESG theme scores and carbon intensity in our cross-section of developed equities, first computed for each portfolio rebalancing date (December 2013 to December 2019), then averaged across time. We consider Spearman rank correlations which are less affected by outliers and more related to the rank-weighted portfolios we will build later on.

Table 1. List of ESG Theme Scores Used in Portfolio Construction.

	E themes	S themes	G themes
MSCI	• Climate Change • Natural Resource Use • Waste Management • Environmental Opportunities	• Human Capital • Product Liability • Social Opportunities	• Corporate Governance • Corporate Behaviour
Refinitiv	• Emissions • Environmental Innovation • Resource Use	• Community • Human Rights • Product Responsibility • Workforce	• CSR Strategy • Management • Shareholders
Moody's	• Environment	• Human Rights • Human Resources • Community Involvement	• Business Behaviour • Corporate Governance

Table 2. Average Cross-Sectional Rank Correlation Between ESG Scores and Carbon Intensity

Average of pairwise correlation between ESG theme scores and Scope 1+2 Carbon Intensity	E Pillar Average	S Pillar Average	G Pillar Average
MSCI ESG themes	-0.24	0.05	0.00
Refinitiv ESG themes	0.04	0.03	0.06
Moody's ESG themes	0.12	0.09	0.07

This table is obtained as follows. First, for every year between December 2013 and December 2019, the cross-sectional pairwise correlation between each ESG theme score and carbon intensity is computed across stocks in the Scientific Beta developed universe. Second, we average these pairwise correlations across years. Third, we average the resulting pairwise correlations within each ESG pillar, e.g. the E pillar average of -0.24 is the arithmetic average of the 2013-2029 average correlations between carbon intensity and the following MSCI ESG scores: Climate Change (-0.17), Natural Resource Use (-0.22), Waste Management (-0.40), and Environmental Opportunities (-0.18). E pillar includes: 4 themes for MSCI, 3 themes for Refinitiv, 1 theme for Moody's ESG. S pillar includes: 3 themes for MSCI, 4 themes for Refinitiv, 3 themes for Moody's ESG. G pillar includes: 2 themes for MSCI, 3 themes for Refinitiv, 2 themes for Moody's ESG, as shown in Table 1.

Only one type of scores has negative correlation to carbon intensity, suggesting that stocks with higher ESG scores will tend to have lower carbon intensities: MSCI environmental themes. However, at -0.24 the negative cross-sectional correlation between carbon intensity and MSCI E scores is far from -1, and we can expect to have green dilution even when adding MSCI environmental theme objectives to a carbon reduction objective. The other types of ESG themes shown in Table 2 do not display any substantial link to carbon intensity. Mixing a carbon reduction objective with such unrelated ESG objectives poses the risk of strong green dilution.

4. Methodology

4. Methodology

Our methodology to assess green dilution has three key steps, which are summarised below.

- **Building a green benchmark**, a portfolio of global developed stocks solely dedicated to reducing carbon intensity: Stocks are weighted using a single input, Scope 1+2 carbon intensity ranks.
- **Building multiple-objectives portfolios:** ESG and carbon mixing portfolios (with weights based on an average of ESG score ranks and carbon intensity ranks), and ESG screening portfolios (with weights based on carbon intensity ranks after excluding a proportion of stocks based on ESG scores).
- **Measuring the green dilution of multiple-objectives portfolios.** This is done in several steps. First, we measure the percentage greenness improvement of the green benchmark compared to the Scientific Beta developed cap-weighted index, using two greenness metrics: the carbon intensity and the carbon sensitivity (regressing stock-level weights on their log carbon intensity[16]). Carbon intensity represents the average greenness of the portfolio, while carbon sensitivity measures the strength and consistency of the relationship between carbon intensity and portfolio weights. Then, we measure the percentage greenness improvement or deterioration of each multiple-objectives portfolio compared with the Scientific Beta developed cap-weighted index using our two greenness metrics. Finally, we compute the green dilution of each multiple-objectives portfolio, measured as its greenness improvement relative to the greenness improvement offered by the green benchmark. Green dilution measures how much of the greenness improvement of the green benchmark remains after the addition of ESG theme scores in portfolio design.

We now explain the three steps required to measure green dilution in detail. To assess the loss of greenness that arises when combining ESG goals with a carbon reduction goal, we first build a green benchmark reflecting a single investor objective: reducing portfolio carbon intensity. The green benchmark is only weighted by stock-level carbon intensity. It is therefore free of other information and cannot be suspected of greenwashing (see Amenc, Goltz, and Liu, 2022). The green benchmark offers the maximum carbon intensity reduction an investor can achieve for a given weighting scheme. The use of such a benchmark is motivated by several factors. Pastor, Taylor, and Stambaugh (2021) show that the optimal portfolio of an agent with green preferences includes a long/short green portfolio, which caters to investors non-pecuniary preferences. The authors additionally show that if green scores indicate low climate risk, the green benchmark is an important building block optimally held by investors who are concerned over hedging climate risk. Our green benchmark can be seen as a long-only implementation of the Pastor, Taylor, and Stambaugh (2021) green factor. Since our green benchmark is only weighted by carbon intensity, we can attribute all the difference in greenness between multiple-objectives portfolios and the green benchmark to the addition of ESG scores in the weighting scheme of multiple-objectives portfolios.

The rank-weighted green benchmark is defined by the following weighting scheme, which results in an unequivocal and direct negative relationship between carbon intensity and portfolio weights. The weight of each stock i in the green benchmark (*gb*) is simply proportional to its descending

16 - Using log helps us obtain a smoother distribution of carbon intensities, which has heavy tails.

4. Methodology

carbon intensity rank: $w_{Rank,t}^{i,gb} = \frac{CI{\downarrow}Rank_t^i}{\sum_{i=1}^{N} i}$, with N the number of stocks in the Scientific Beta developed universe with both carbon intensity and ESG scores available at annual rebalancing date t, and $CI \downarrow Rank_t^i$ the descending cross-sectional rank of stock i by Scope 1+2 Carbon Intensity at date t. All our portfolios (green benchmark as well as multiple-objectives portfolios) are weighted and rebalanced annually in December, from December 2013 to December 2019.

To build ESG and carbon mixing portfolios, we build rank-weighted portfolios adding ESG scores to carbon intensity in a composite score, which is the average cross-sectional rank of carbon intensity and ESG score. This approach is inspired by methodologies used in the investment industry where carbon and ESG scores are mixed as weight determinants[17]. The construction process of the ESG and carbon mixing portfolios is thus similar to that of the green benchmark, with only one difference: the addition of ESG score ranks in the weighting scheme. Rank-weighted ESG and carbon mixing portfolios have stock weights that are proportional to the average of the cross-sectional descending carbon intensity (CI) rank and the ascending ESG theme score rank of each stock, for a given combination of ESG scores x:

$$w_{Rank,t}^{i,Mixing\ x} = \frac{\frac{1}{T+1}(CI{\downarrow}Rank_t^i + ESG{\uparrow}Rank_t^{i,theme\ 1} + ESG{\uparrow}Rank_t^{i,theme\ 2} + \cdots + ESG{\uparrow}Rank_t^{i,theme\ T})}{\sum_{i=1}^{N} i}$$

These portfolios allow us to measure the incremental impact the inclusion of ESG objectives (scores) has on the climate objective (carbon reduction). For instance, a portfolio built using one ESG theme score will have its weight 50% determined by carbon intensity and 50% determined by the ESG score in question. As we add more ESG theme scores to the weighting formula, the climate objective should become more and more diluted, and we are interested in quantifying this dilution. We test many strategies combining different ESG scores with carbon intensity. Assessing an extensive set of possible ESG theme combinations allows us to derive results that can be generalised. We create three different groups of ESG and carbon mixing portfolios:

- **Group 1:** portfolios mixing a single ESG theme score with carbon intensity. We should expect dilution to be moderate, since the climate objective will be diluted by one and only one ESG goal in each portfolio from group 1, with carbon intensity still accounting for half of the stock weights determination. Since we have 25 ESG themes in total, group 1 includes 25 portfolios.
- **Group 2:** portfolios mixing all themes in a given pillar (E, S or G) with carbon intensity. Group 2 reflects an investor's objective to account for all themes in each pillar (E, S or G) and to combine them with carbon intensity. This represents the ESG preferences of a pillar-focused investor, or in more practical terms a thematic investor. Group 2 portfolios will have their weights determined by a varying number of ESG scores depending on the rating provider and pillar in question, e.g. the portfolio built using all MSCI environmental (E) themes will have its weight 80% determined by the four available MSCI E themes (see Table 1) and 20% determined by carbon intensity. We have three pillars (E, S, G) for three ESG rating providers, resulting in nine portfolios for group 2.
- **Group 3:** portfolios that add cumulative combinations of ESG themes from different pillars, selected by their green dilution potential as measured by correlation with carbon intensity. Cumulative additions of ESG theme scores in portfolio construction will result in different green

17 - Examples of indices that determine weights as a function of both carbon and ESG scores include the FTSE ESG Low Carbon Select Indexes and the FTSE All Share ex Investment Trusts ESG Climate Select Index. Moreover, quantitative tools that allow investors to construct equity portfolios frequently accommodate functions such as targeting a composite score created by equal-weighting different signals. While these signals traditionally were accounting fundamentals (such as price earnings ratios and profitability scores), they can now be replaced by non-financial scores such as carbon intensity and corporate governance score.

4. Methodology

dilution levels based on the first scores we consider. If we first add themes that are most negatively (respectively positively) correlated to carbon intensity in the cross section of stocks, the resulting portfolios will potentially have lower (respectively higher) green dilution. We therefore create one set of portfolios adding theme scores starting with the most negatively correlated to carbon intensity, and one set of portfolios adding theme scores starting with the most positively correlated to carbon intensity. For each ESG rating provider, we start with portfolios built using carbon intensity and the two scores[18] that are the most negatively correlated to carbon intensity in our cross section of stocks, which results in a portfolio with weights that are 2/3rds determined by ESG theme scores and 1/3rd by carbon intensity. We then add one ESG score at a time, in order of rising score correlation to carbon intensity, which will gradually reduce the impact of carbon intensity on stock-level weights. We also create portfolios incrementally adding ESG theme scores ranked from most positively to most negatively correlated to carbon intensity, to assess greenness when building portfolios based on the ESG theme scores that are a priori least compatible with carbon reduction. We obtain 22 portfolios cumulatively adding ESG theme scores by increasing correlation to carbon intensity, and another 22 by decreasing correlation, resulting in a total of 44 portfolios for group 3.

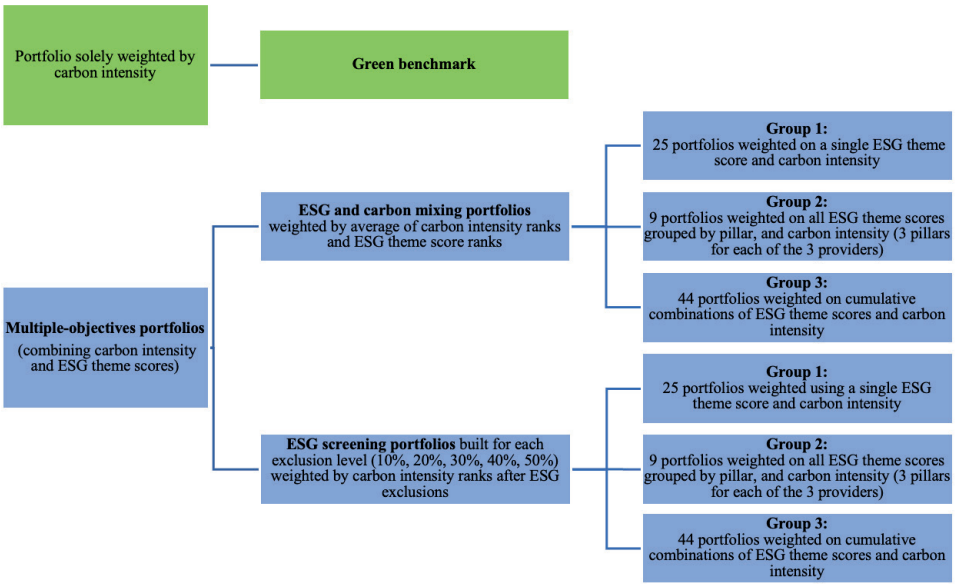
Portfolios in each group will be built separately using each of the three ESG data providers, for a total of 78 portfolios[19]. Note that we never mix theme scores across providers in portfolio construction since each rating company has different methodologies, and themes are therefore not directly comparable. Portfolios from groups 2 and 3 can have their carbon intensity diluted by different numbers of ESG themes depending on which provider is considered, since we do not have the same number of scores for each provider. We test portfolios controlling for the different number of ESG themes across providers as part of our robustness tests.

An alternative way of integrating ESG into investment strategies is ESG screening: instead of weighting stocks by ESG scores, ESG "worst offenders", as determined by ESG criteria, are screened out from portfolios. An ESG screening mechanism keeps ESG characteristics separate from other portfolio objectives. We test the ESG screening approach by building additional sets of our 78 rank-weighted portfolios, using the same combinations of ESG themes we used for ESG and carbon mixing portfolios. We screen out stocks with the lowest average ESG theme score, computed based only on the scores considered in each one of our 78 theme scores combinations, for different exclusion levels (10%, 20%, 30%, 40%, and 50%) and then weight the remaining stocks solely by carbon intensity ranks. This results in 78 portfolios for each exclusion level. These portfolios are directly comparable to the portfolios built using mixed scores as they exploit the same ESG and carbon information. Each of these ESG screening portfolios uses the same set of ESG theme scores as the corresponding ESG and carbon mixing portfolio, but unlike the mixing approach, here we do not average ranks between ESG scores and carbon intensity. These ESG screening portfolios follow the same weighting scheme as the green benchmark, but on a restricted universe of stocks, after filtering out the ones with the lowest average ESG scores. We summarise the portfolios we create in Figure 1.

18 - Portfolios including the least correlated single ESG score from each of our three providers are already included in group 1, which is why group 3 has two sets of 25 – 3 = 22 portfolios.
19 - The list of ESG themes included in each of our 78 portfolios is included in Appendix 4.

4. Methodology

Figure 1. Overview of Portfolios Built to Measure Green Dilutions



Once we have built a green benchmark (weighted only by carbon intensity) and multiple-objectives portfolios (incorporating both ESG scores and carbon intensities), we measure their respective greenness using two simple metrics. The first one is the average carbon intensity, computed as follows for each portfolio (green benchmark, mixing, and screening portfolios alike):

$$\overline{WACI} = \frac{\sum_{t=1}^{T}\left(\sum_{i=1}^{N}\left(w_t^i CI_t^i\right)\right)}{T},$$

with *t* the annual December rebalancing date from 2013 to 2019 (we have T = 7 years in total), *N* the number of stocks in portfolio at time *t*, w_t^i the weight of stock *i* in portfolio at time *t*, and CI_t^i the carbon intensity of stock *i* at time *t*. We use Scope 1+2 carbon intensity in our base specification, which is the standard investor metric to assess the greenness of portfolios, as recommended by the Task Force on Climate-related Financial Disclosures (TCFD, 2021). Measuring greenness based on carbon emissions normalised by revenues is also more stable than other commonly used metrics, such as carbon emissions normalised by total enterprise value (see Ducoulombier and Liu, 2021). WACI shows the average carbon intensity of the portfolio, but it can be influenced by outliers and does not measure the stock-level alignment of individual weights to carbon intensity.

As an alternative greenness measure to WACI, we also measure the strength of the (negative) relationship between carbon intensity and portfolio weights with the carbon sensitivity. This metric is similar in spirit to the weight determinant analysis proposed by Amenc, Goltz, and Liu (2022), and will help us determine how consistently stock-level weights are determined by carbon intensity. We denote carbon sensitivity by the *S* coefficient in the following pooled regression run for each portfolio (pooling across stocks and years for a given portfolio). Using the same notation as the $\overline{WACI}$ formula we have:

$$w_t^i = \alpha + S \ln(CI_t^i) + \varepsilon_t^i$$

4. Methodology

Our rank-based weighting scheme results in an inverse exponential relationship between carbon intensity (CI_t^i) and weights (w_t^i), and the distribution of carbon intensities is noisy with heavy tails. For these reasons, we use the natural logarithm of carbon intensities in our regressions.

We now have all the ingredients required to assess green dilution. We report green dilution for each of our two greenness metrics and the overall green dilution as the arithmetic average across both metrics. For each portfolio, green dilution is computed in several steps for each greenness metric. First, we compute the percentage greenness improvement of the green benchmark relative to the cap-weighted index, which represents its *green performance*. For instance, if the average scope 1+2 WACI of the green benchmark is 43 tons of CO2 equivalent per million of USD revenue, while that of the cap-weighted index is 191, then the green performance of the green benchmark is a 78% reduction in carbon intensity (43/191-1). Similarly, we then compute the green performance of multiple-objectives portfolios relative to the cap-weighted index (variation in greenness metric compared to the cap-weighted index). Armed with green performance for both the green benchmark and the multiple-objectives portfolios, we are able to express the green performance of multiple-objectives portfolios relative to the green performance of the green benchmark, which gives our green dilution metric.

Green dilution measures how much of the greenness improvement that is achievable with the green benchmark is captured by multiple-objectives portfolios (in percentage terms). For example, a green dilution value of 0% means that the carbon intensity reduction of a multiple-objective portfolio equals that of the green benchmark. A green dilution value of 50% means that the multiple-objective portfolio only delivers half the carbon intensity reduction that would be possible with the green benchmark. A green dilution value of 100% indicates that a portfolio has the same greenness as the cap-weighted index, losing all carbon reduction benefits that would be possible with the green benchmark. A value of 110% indicates that the portfolio not only foregoes some of the carbon reduction potential of the green benchmark, but increases carbon intensity (or reduces carbon sensitivity) by 10% relative to the cap-weighted index.

More specifically, we compute green dilution as one minus the ratio of the green performance of a multiple-objective portfolio to the green performance of the green benchmark. For a portfolio built based on carbon intensity and a given x combination of ESG scores we get the following green dilutions (one per green dilution metric):

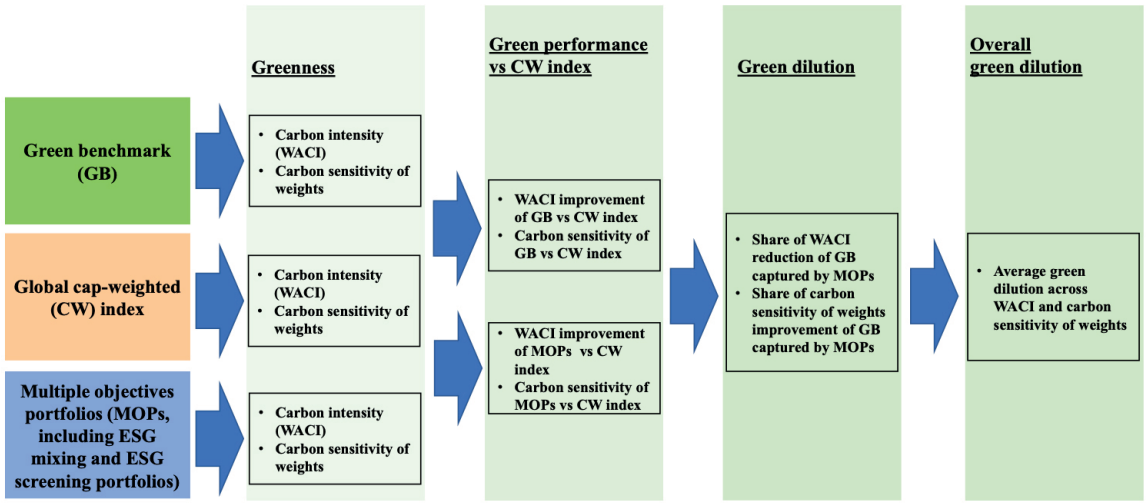
$$Green\ Dilution^{\overline{WACI}}_{Portfolio\ x} = 1 - \frac{\frac{\overline{WACI}_{Portfolio\ x}}{\overline{WACI}_{Cap-weighted}} - 1}{\frac{\overline{WACI}_{Green\ Benchmark}}{\overline{WACI}_{Cap-weighted}} - 1} \quad (1)$$

$$Green\ Dilution^{S}_{Portfolio\ x} = 1 - \frac{\frac{S_{Portfolio\ x}}{S_{Cap-weighted}} - 1}{\frac{S_{Green\ Benchmark}}{S_{Cap-weighted}} - 1} \quad (2)$$

4. Methodology

We summarise our green dilution measurement process in Figure 2.

Figure 2. Green Dilution Measurement Process



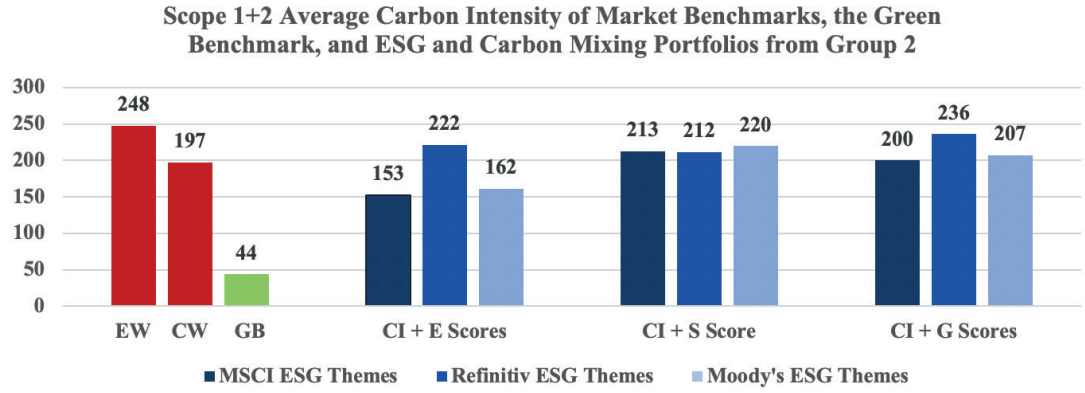
4. Results

4. Results

We first report the greenness of portfolios separately for each greenness metric (carbon intensity and carbon sensitivity). In Figure 3 we report the Scope 1+2 carbon intensity of market benchmarks (developed cap-weighted and equal-weighted indices), the green benchmark, and - for conciseness – the ESG and carbon mixing portfolios focusing on different ESG pillars[20] (group 2). Group 2 includes three portfolios, one per ratings provider, for each ESG pillar. We thus have three portfolios for the E pillar, each one weighted based on the average rank of carbon intensities and all E theme scores from a single rating provider (MSCI, Refinitiv, and Moody's). Similarly, we obtain three portfolios for the S pillar, and three portfolios for the G pillar.

The cap-weighted developed index has an average carbon intensity of 197 tons of C02 equivalent per million of USD revenue (as shown on left-hand side of Figure 3), which is the baseline carbon intensity of market indices that do not have any objective of carbon reduction. The equal-weighted index has a higher carbon intensity, at 248, suggesting a negative link between market capitalisation and carbon intensity. The green benchmark, weighted solely to reduce carbon intensity, with a carbon intensity of 44 tons per million USD of revenue, achieves a sizable carbon intensity reduction of 78% compared to the CW index. This green performance is the denominator in Equation 1 above and will be our reference to measure the green dilution in terms of carbon intensity for all multiple-objectives portfolios.

Figure 3. Average 2013-2020 Carbon Intensity of ESG and Carbon Mixing Portfolios Weighted by Carbon Intensity and All ESG Theme Scores by Pillar (Group 2)



EW: Scientific Beta equal-weighed developed index. CW: Scientific Beta cap-weighted developed index. GB: green benchmark. This chart shows average Scope 1+2 weighted average carbon intensities ($\overline{WACI}$) reported in tons of CO2 equivalent per million USD revenues. Carbon intensities (CI) are computed annually for each individual portfolio (78 in total) and averaged from December 2013 to December 2019. The Environment (E) pillar include 4 themes for MSCI, 3 themes for Refinitiv, 1 theme for Moody's ESG. The Social (S) pillar include 3 themes for MSCI, 4 themes for Refinitiv, 3 themes for Moody's ESG. The Governance (G) pillar include 2 themes for MSCI, 3 themes for Refinitiv, 2 themes for Moody's ESG. See Table 1 for details.

Turning to ESG and carbon mixing portfolios from group 2, we observe dramatic increases in carbon intensity when mixing ESG theme scores with carbon objectives. These increases even occur when considering only environmental themes. In fact, the inclusion of ESG theme scores that belong to the Environmental (E) pillar results in dramatic increases in carbon intensity compared to the green benchmark. The carbon intensities of these portfolios are about four to five times higher than for the green benchmark. The portfolio created using carbon intensity and Refinitiv E theme scores even

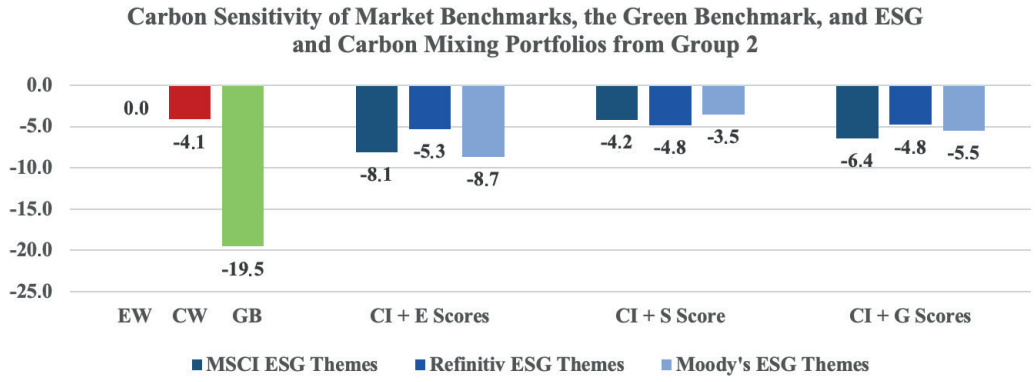
20 - The greenness of individual portfolios from all groups (groups 1, 2, and 3) are available in our online supplement, along with sector and country deviations compared to the developed cap-weighted index and performance for our main portfolios.

4. Results

has a higher carbon intensity than the cap-weighted index. The two portfolios built with carbon intensity and MSCI or Moody's E theme scores have carbon intensities that were multiplied by a factor of four compared with the green benchmark (built only using carbon intensity). Adding S or G theme scores to carbon intensity in our rank-based weighing scheme systematically results in carbon intensity increases relative to the cap-weighted index. In other words, adding S or G theme scores to portfolio construction has more than offset the inclusion of carbon intensity as a weight determinant. Note that these ESG and carbon mixing portfolio all explicitly have a share of their weights that tilts towards low-carbon-intensity stocks, due to the inclusion of carbon intensity ranks in the average rank that determines portfolio weights. Yet, the addition of ESG scores as a weight determinant resulted in carbon intensity increases compared to the cap-weighted index.

Our second greenness metric, carbon sensitivity (linear regression coefficient from a regression of portfolio weights on carbon intensities) gives us a way to measure the stock-level consistency of the carbon reduction objective. Figure 4 shows the carbon sensitivity of market benchmarks, the green benchmark, and ESG and carbon mixing portfolios from group 2. Looking at market benchmarks, we notice that the green tilt of the developed cap-weighted index (lower carbon intensity than the equal-weighted index) is confirmed by carbon sensitivity. The equal-weighted index has a carbon sensitivity of 0 and is truly carbon agnostic, but the cap-weighted index has a negative and significant coefficient[21] of -4.1, indicating a negative relationship between carbon intensity and market capitalisations. The green benchmark achieves a substantial improvement in carbon sensitivity of 373.4% (from -4.1 to -19.5) compared to the CW index, which is the denominator in (2).

Figure 4. Carbon Sensitivity of ESG and Carbon Mixing Portfolios Weighted by Carbon Intensity and All ESG Theme Scores by Pillar (Group 2)



EW: Scientific Beta equal-weighed developed index. CW: Scientific Beta cap-weighted developed index. GB: green benchmark. Carbon sensitivity of weights estimated from the following pooled regression run separately for each portfolio: 100,000 $* w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability. w_t^i is the weight of stock i at rebalancing date t, CI_t^i its carbon intensity. The Environment (E) pillar include 4 themes for MSCI, 3 themes for Refinitiv, 1 theme for Moody's ESG. The Social (S) pillar include 3 themes for MSCI, 4 themes for Refinitiv, 3 themes for Moody's ESG. The Governance (G) pillar include 2 themes for MSCI, 3 themes for Refinitiv, 2 themes for Moody's ESG. See Table 1 for details.

The carbon sensitivities of portfolios confirm our results based on carbon intensity. E themes, which one might have expected to be green, make portfolio weights two to five times less sensitive to carbon intensity than they would be weighting stocks only by carbon intensity (as is done in the

21 - Our online supplement includes the carbon sensitivity of all individual portfolios and their associated t-stats (based on White standard errors).

4. Results

green benchmark). Adding social (S) themes to carbon intensity in our weighting scheme appears particularly detrimental since it results in carbon sensitivities close to that of the cap-weighted index. Portfolios using governance (G) scores remain greener than the cap-weighted index, with more negative carbon sensitivities, although they are far from the green benchmark level.

Figures 3 and 4 showed greenness results focusing on ESG and carbon mixing portfolios from group 2, which allowed us to measure the loss of greenness resulting from the inclusion of ESG theme scores grouped by pillar, including environmental ones. In Table 3 we report greenness and green dilution based on carbon intensity and carbon sensitivity, for benchmarks (cap-weighted index and green benchmark) and all ESG and carbon mixing portfolios across our three portfolio groups.

Panel A. (upper half of Table 3) shows greenness and green dilution based on carbon intensity. If we evaluate portfolio greenness solely based on carbon intensity, which is common investor practice, the carbon reduction potential of the green benchmark is entirely diluted by ESG scores, with the bottom right of Panel A. showing a 99.1% green dilution computed on average across our three groups of 78 portfolios and years from 2013 to 2019. Green dilution close to 100% implies a carbon intensity in line with the cap-weighted index, in other words ESG scores cancelled out the impact of carbon intensity scores in portfolio construction. Dilution is significant even when adding a single ESG score objective in portfolio construction, with a 70.9% average green dilution based on carbon intensity for portfolios of group 1 (bottom row of Panel A). This is stunning since the weights of group 1 portfolios are 50% determined by carbon intensity. When adding more than one ESG theme score from Refinitiv or Moody's in portfolio weighting schemes, we obtain portfolios that are more carbon intensive than the cap-weighted index (green dilution based on carbon intensity above 100% for groups 2 and 3). In other words, ESG objectives have completely crushed the carbon reduction objective in these portfolios, to the point where carbon intensity stopped having any noticeable impact on portfolio weights. Portfolio weights were moved far away from their optimal carbon reduction levels, which are the weights of the green benchmark. In fact, portfolio weights were moved even farther from optimal carbon reduction levels than the weights of the cap-weighted index, which is remarkable since the cap-weighted index does not incorporate any carbon intensity information in its weighting scheme. The results also confirm the initial correlation findings from Table 1: only MSCI themes appear to generate less dilution than other ESG themes like Refinitiv's or Moody's. However, the improvement is small: MSCI theme scores on average result in a green dilution of 86.2% (based on carbon intensity, rightmost column in Panel A.), while scores from other providers routinely result in green dilutions over 100%.

Panel B (lower half of Table 3) shows greenness and green dilution based on carbon sensitivity. Based on that second metric, adding ESG score objectives to a carbon reduction objective dilutes 85.4% of the green benchmark's carbon sensitivity in developed equity portfolios (bottom right of Panel B.). Carbon sensitivity shows a slightly less severe green dilution than carbon intensity, but green dilution remains remarkably high, close to 100% for portfolios including more than one ESG theme.

4. Results

Averaging green dilution across all 78 combinations of ESG theme scores and two green dilution metrics, we get to an overall green dilution of 92.2% (bottom right of Table 3). In other words, adding combinations of ESG theme scores to carbon intensity as a weight determinant in developed equity portfolios dilutes 92.2% of the initial carbon reduction objective. Only 7.8% of the carbon reduction objective survived ESG scores.

Table 3. Greenness and Green Dilution of Benchmarks, and ESG and Carbon Mixing Portfolios

	Developed Cap-weighted Index	Green Benchmark	ESG Ratings Provider	Portfolio group 1 (Combining a single ESG score and CI)	Portfolio group 2 (Combining all scores by E or S or G pillar and CI)	Portfolio group 3 (Cumulatively adding ESG scores to CI)	Average across 3 groups
Panel A: Carbon Intensity							
Greenness (Scope 1+2 WACI)	197	44	MSCI	137	188	196	176
			Refinitv	161	223	235	209
			Moody's	163	196	228	199
Green Performance (Scope 1+2 WACI change vs CW index)	0.0%	-77.9%	MSCI	-30.2%	-4.4%	-0.4%	-10.8%
			Refinitv	-18.4%	13.3%	19.3%	6.1%
			Moody's	-17.5%	-0.5%	15.7%	1.0%
Green Dilution based on Scope 1+2 WACI	100.0%	0.0%	MSCI	61.2%	94.4%	99.5%	86.2%
			Refinitv	76.4%	117.0%	124.8%	107.9%
			Moody's	77.5%	99.3%	120.2%	101.2%
Average Green Dilution based on WACI	100.0%	0.0%		70.9%	103.6%	114.5%	99.1%
Panel B: Carbon Sensitivity							
Greenness (Carbon Sensitivity)	-4.1	-19.5	MSCI	-10.8	-6.2	-5.2	-7.2
			Refinitv	-11.3	-5.0	-3.6	-6.3
			Moody's	-8.9	-5.9	-3.0	-5.3
Green Performance (Greenness change vs cap-weighted index)	0.0%	373.4%	MSCI	160.8%	51.0%	27.1%	74.3%
			Refinitv	172.8%	20.4%	-12.2%	52.7%
			Moody's	115.7%	42.3%	-27.3%	27.4%
Green dilution based on carbon sensitivity	100.0%	0.0%	MSCI	56.9%	86.3%	92.7%	80.1%
			Refinitv	53.7%	94.5%	103.3%	85.9%
			Moody's	69.0%	88.7%	107.3%	92.7%
Average Green Dilution based on carbon sensitivity	100.0%	0.0%		58.5%	89.8%	100.3%	85.4%
Overall Green Dilution	**100.0%**	**0.0%**		**64.5%**	**96.7%**	**107.4%**	**92.2%**

*This table shows the greenness and green dilution of our ESG and carbon mixing portfolios, based on two greenness metrics: the Weighted Average Carbon Intensity (WACI, expressed in annual tons of CO2 equivalent per million of USD revenues) and the carbon sensitivity of weights. Averages across portfolios are computed giving the same weight to each portfolio representing a unique combination of ESG themes and carbon intensity, and no portfolios are double counted. The carbon sensitivity of weights is estimated from the following pooled regression run separately for each portfolio: 100,000 * $w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$, with w_t^i the weight of stock i at rebalancing date t, CI_t^i its carbon intensity, and weights multiplied by 100,000 for better readability. Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. A green dilution equal to 100% means that the portfolio has the same greenness as the cap-weighted index. A green dilution above 100% indicates a greenness deterioration compared to the cap-weighted index. The full list of portfolios included in each group (one for each ESG theme combination) is available in Appendix 4. The averages are computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 21 (all MSCI themes are also in portfolio 12), 51 (all Refinitiv themes are also in portfolio 41), 74 (all Moody's themes are also in portfolio 68), and 78 (Moody's lone Environmental score is also in portfolio 60).*

4. Results

We now turn to the greenness and green dilution of ESG screening portfolios, which, instead of mixing ESG scores and carbon intensity in the weighting scheme, first exclude stocks with the lowest ESG scores before weighting the remaining stocks solely based on carbon intensity. Our focus is to compare the green dilution resulting from a screening approach to that resulting from a mixing approach. As investors may also be concerned by the level of ESG scores of their portfolios, it is relevant to point out that ESG screening at 20% to 30% of stocks achieves the same level of average ESG score as ESG mixing portfolios (see Appendix 3 for average ESG scores for each ESG theme combination of mixing and screening portfolios).

The right-hand side column of Table 4 below shows screening out stocks with the lowest average ESG scores leads to negligible levels of green dilution: weighting stocks based on carbon intensity with ESG screening produces portfolios that are essentially as green as our green benchmark, with an overall green dilution below 1.5% for any level of ESG exclusion. The average green dilution across ESG screening portfolios is minimal, at 0.4% based on carbon intensity, 1.1% based on carbon sensitivity, and 0.8% overall across these two metrics (bottom row).

Table 4. Greenness and Green Dilution of ESG Screening Portfolios

Average metric across ESG screening portfolios	Scope 1+2 WACI	Green dilution based on Scope 1+2 WACI	Carbon sensitivity of weights	Green dilution based on carbon sensitivity of weights	Overall green dilution
Developed cap-weighted index	197	100.0%	-4.1	100.0%	100.0%
Green benchmark	44	0.0%	-19.5	0.0%	0.0%
ESG and carbon mixing portfolios	196	99.1%	-6.4	85.4%	92.2%
Portfolios with 10% ESG score screening	44	0.1%	-19.5	0.4%	0.2%
Portfolios with 20% ESG score screening	44	0.2%	-19.5	0.4%	0.3%
Portfolios with 30% ESG score screening	44	0.4%	-19.3	1.3%	0.9%
Portfolios with 40% ESG score screening	45	0.7%	-19.2	1.9%	1.3%
Portfolios with 50% ESG score screening	45	0.8%	-19.3	1.4%	1.1%
Average across all ESG screening portfolios	**44**	**0.4%**	**-19.4**	**1.1%**	**0.8%**

All portfolios based on the Scientific Beta universe of developed stocks. All averages are computed giving the same weight to each of the 78 ESG portfolio included in each mixing or screening portfolio groups, without double counting any portfolio. The full list of portfolios (one for each ESG theme combination) is available in Appendix 4. Green dilution based on WACI equals one minus the average % WACI change of ESG mixing/screening portfolios compared to the cap weighted (CW) index, divided by the % WACI reduction of the green benchmark compared to the CW index. A green dilution equal to -100% means that the portfolio has the same carbon sensitivity of weights as the cap-weighted index. The carbon sensitivity of weights is estimated from the following pooled regression run separately for each one of the 78 portfolios comprising each mixing and screening portfolio group: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability. w_t^i is the weight of stock i at rebalancing date t, CI_t^i its carbon intensity. Green dilution based on the carbon sensitivity of weights equals one minus the % change in carbon sensitivity of weights of ESG mixing portfolios compared to the cap weighted index, divided by the carbon sensitivity of weights % increase of the green benchmark (CI only portfolio) compared to the cap weighted index.

Despite using the exact same information, carbon intensity and ESG scores, mixing and screening approaches result in completely different levels of green dilution. Green dilution is much stronger when ESG scores are mixed with carbon intensity in the weighting scheme (overall green dilution of 92.2%, see right-hand side of Table 4) than with ESG score exclusions (overall green dilution of 0.8%

4. Results

on average, see bottom right of Table 4). In other words, investors can avoid green dilution and stay both green and ESG by resorting to ESG exclusions and keeping their weighting scheme focused on carbon intensity only. The key difference is that ESG and carbon mixing averages two unrelated metrics (ESG scores and carbon intensity), naturally diluting the importance of carbon intensity in determining stock-level weights. ESG screening, on the other hand, excludes stocks with various levels of carbon intensities since there is no relation between ESG scores and carbon intensity. This leaves a post-exclusion stock universe with a distribution of carbon intensities that is similar to that of the full stock universe. Weighting stocks by carbon intensity ranks only within this restricted universe thus results in a similar carbon intensity to that obtained with the full universe (weighting stocks by carbon intensity ranks using the full stock universe results in the green benchmark). For instance, the Scientific Beta developed universe resulting from the exclusion of the bottom 50% stocks by the average of all MSCI theme scores has a very small difference in mean log carbon intensity and standard deviation of log carbon intensities with the full developed universe. This holds for lower ESG score exclusion thresholds and at any rebalancing date between 2013 and 2019.

5. Robustness Tests

5. Robustness Tests

We have shown strong levels of green dilution in our ESG and carbon mixing portfolios, across different ESG scores (using 3 rating providers for a total of 25 ESG theme scores) and ESG score combinations (78 portfolios in total).

For robustness, we consider other portfolios that could represent the ESG preferences of investors, based on alternative choices in portfolio design. The first alternative choice is the weighting scheme. We have previously used a rank-based weighting scheme, which remains a stylised strategy. In practice, portfolio optimisation is popular among index providers and quantitative investment strategies when it comes to ESG integration. We test an optimised weighting scheme aiming to increase ESG scores and lower carbon intensity, while maintaining diversification and limiting deviations relative to the cap-weighted index. This different weighting scheme results in an optimised green benchmark, and optimised ESG and carbon mixing portfolios (see Appendix 4. for the detailed methodology). Another alternative choice can be made regarding the carbon emission scope that we use. We test portfolios built based on Scope 1+2+3 carbon emissions instead of Scope 1+2 emissions, and we use scope 1+2+3 carbon emissions for both portfolio construction and measuring green dilution. Finally, the last alternative specification we test is to control for the varying number of ESG scores across data providers. We cap the maximum number of themes in portfolio combinations to 6 (our lowest number of ESG score per provider, which is the number of Moody's scores), to avoid comparing portfolios with different numbers of ESG objectives. For instance, MSCI has four theme scores in its environmental pillar while we only have one environmental score for Moody's, so naturally we should expect dilution to be stronger when more ESG theme scores are included. We explain how we control for different numbers of ESG scores across ESG rating providers in detail in Appendix 5.

These three alternative choices combined create six possible types of ESG and carbon mixing portfolios, for which we report green dilution in Table 5. One portfolio type is simply our base specification: rank-weighted portfolios using Scope 1+2 carbon intensity, without controlling for the different number of ESG theme scores across providers. Table 5 shows green dilution for our base specification as well as the five types of robustness portfolios, and the average green dilution across all robustness portfolios (last column). Note that each of the six portfolio types includes 78 combinations of ESG theme scores, and we report the average green dilution across the 78 portfolios for each portfolio type.

We can see that optimised portfolios are able to somehow reduce green dilution compared with rank weighting, with overall dilution (bottom row in Table 5) falling from 92.2% to 66.0% using scope 1+2 carbon intensity, and from 84.4% to 61.4% using scope 1+2+3 carbon intensity. That lower green dilution is achieved thanks to a less mechanical weighting scheme than our rank-weighted portfolios. The impact of changing from Scope 1+2 to Scope 1+2+3 carbon emissions is small. Surprisingly, the impact of controlling for the varying number of ESG themes across different providers also had a small effect on overall green dilution, since it only went down from 92.2% to 85.7% using rank-weighted portfolios, and from 66.0% to 57.4% using optimised portfolios. This limited reduction in green dilution shows that the key driver of green dilution is the low correlation of ESG theme scores to both other theme scores and carbon intensity. Capping the number of ESG themes scores used in weighting

5. Robustness Tests

schemes at six results in an overall green dilution of 85.7% using our rank-based weighting scheme (bottom row of Table 5) and capping the number of scores used at one results in a green dilution of 64.5% (overall green dilution for group 1 in Table 4). In both cases, the vast majority of carbon reduction is lost. Overall, robustness portfolios confirm the presence of strong green dilution, albeit with a moderate decrease compared to our base specification, with overall green dilution falling from 92.2% to 71.0% (bottom row of Table 5). Across all portfolio specifications, the minimum overall dilution is close to 60%, which remains considerable.

Table 5. Green Dilution of ESG and Carbon Mixing: Robustness Tests

	Base specification	Robustness portfolios					
	Scope 1+2, rank weighted	Scope 1+2, optimised	Scope 1+2, controlling for # of scores, rank weighted	Scope 1+2, controlling for # of scores, optimised	Scope 1+2+3, rank weighted	Scope 1+2+3, optimised	Average green dilution of robustness portfolios
Green dilution based on carbon intensity	99.1%	67.0%	92.2%	57.4%	86.0%	59.3%	**72.4%**
Green dilution based on carbon sensitivity	85.4%	65.1%	79.2%	57.4%	82.9%	63.5%	**69.6%**
Overall green dilution	**92.2%**	**66.0%**	**85.7%**	**57.4%**	**84.4%**	**61.4%**	**71.0%**

Note: all portfolios based on the Scientific Beta universe of developed stocks. All averages are computed giving the same weight to each portfolio, without double counting any portfolio. The full list of portfolios (one for each ESG theme combination) is available in Appendix 4. Detailed greenness and green dilution results for all individual portfolios included in each specification are available in our online supplement. Portfolios controlling for a different number of scores across ESG providers include 55 portfolios as explained in Appendix 5. Green dilution based on WACI equals one minus the average % WACI change of ESG mixing portfolios compared to the cap weighted (CW) index, divided by the % WACI reduction of the green benchmark compared to the CW index. A green dilution equal to -100% means that the portfolio has the same carbon sensitivity of weights as the cap-weighted index. WACI dilution is measured using Scope 1+2 emissions. The carbon sensitivity of weights is estimated from the following pooled regression run separately for each one of the 78 portfolios: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability. w_t^i is the weight of stock i at rebalancing date t, CI_t^i its carbon intensity. Green dilution based on the carbon sensitivity of weights equals one minus the change in carbon sensitivity of weights of ESG mixing portfolios compared to the cap weighted index, divided by the carbon sensitivity of weights increase of the green benchmark compared to the cap weighted index.

We test the same alternative choices in portfolio design using the ESG screening approach, and present results in Table 6. For each ESG exclusion level and specification, we build 78 ESG screening portfolios and report the average green dilution across portfolios below. These portfolios are weighted solely by carbon intensity ranks, but on the restricted stock universe resulting from the exclusion of stocks with the lowest average ESG score for each of our 78 ESG score combinations. We find robustness ESG screening portfolios have almost the exact same green dilution as our base specification when measured using carbon intensity, with an average of 0.3% (right hand side of Table 6), compared to 0.4% (bottom row of Table 4). When using carbon sensitivity instead, we see only a limited increase in green dilution to 3.8% (right hand side of Table 6), from 1.1% (bottom row of Table 4). Green dilution levels in ESG screening portfolios under any specification remain negligible compared to the ESG and carbon mixing approach, confirming the practical advantage of ESG screening compared to ESG and carbon mixing.

5. Robustness Tests

Table 6. Green Dilution of ESG Screening: Robustness Tests

	Base specification	Robustness portfolios					
	Scope 1+2, rank weighted	Scope 1+2, optimised	Scope 1+2, controlling for # of scores, rank weighted	Scope 1+2, controlling for # of scores, optimised	Scope 1+2+3, rank weighted	Scope 1+2+3, optimised	Average green dilution of robustness test portfolios
Panel A: Green dilution based on carbon intensity							
10% ESG score screening	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	**0.0%**
20% ESG score screening	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	**0.1%**
30% ESG score screening	0.4%	0.2%	0.5%	0.3%	0.3%	0.2%	**0.3%**
40% ESG score screening	0.7%	0.4%	0.8%	0.4%	0.6%	0.3%	**0.5%**
50% ESG score screening	0.8%	0.5%	0.9%	0.6%	0.6%	0.4%	**0.6%**
Average	0.4%	0.3%	0.5%	0.3%	0.3%	0.2%	**0.3%**
Panel B: Green dilution based on carbon sensitivity							
10% ESG score screening	0.4%	5.0%	0.0%	5.0%	0.4%	5.2%	**3.1%**
20% ESG score screening	0.4%	4.7%	0.0%	4.9%	0.7%	5.1%	**3.1%**
30% ESG score screening	1.3%	5.1%	1.3%	5.8%	1.8%	5.7%	**4.0%**
40% ESG score screening	1.9%	5.3%	2.3%	6.4%	2.7%	6.1%	**4.6%**
50% ESG score screening	1.4%	5.2%	1.7%	6.1%	2.5%	6.2%	**4.3%**
Average	1.1%	5.1%	1.1%	5.7%	1.7%	5.7%	**3.8%**
Overall green dilution	**0.8%**	**2.7%**	**0.8%**	**3.0%**	**1.0%**	**2.9%**	**2.1%**

*Note: all portfolios based on the Scientific Beta universe of developed stocks. All averages are computed giving the same weight to each portfolio, without double counting any portfolio. The full list of portfolios (one for each ESG theme combination) is available in Appendix 4. Portfolios controlling for a different number of scores across ESG providers include 55 portfolios as explained in Appendix 5. Green dilution based on WACI equals one minus the average % WACI change of ESG mixing portfolios compared to the cap weighted (CW) index, divided by the % WACI reduction of the green benchmark compared to the CW index. A green dilution equal to -100% means that the portfolio has the same carbon sensitivity of weights as the cap-weighted index. WACI dilution is measured using Scope 1+2 emissions. The carbon sensitivity of weights is estimated from the following pooled regression run separately for each one of the 78 portfolios for a given ESG exclusionary level: 100,000 * $w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability. w_t^i is the weight of stock i at rebalancing date t, CI_t^i its carbon intensity. Green dilution based on the carbon sensitivity of weights equals one minus the change in carbon sensitivity of weights of ESG mixing portfolios compared to the cap weighted index, divided by the carbon sensitivity of weights increase of the green benchmark compared to the cap weighted index.*

6. Conclusion

6. Conclusion

Research on ESG and climate investing mainly focusses either on the relationship between ESG or climate metrics and expected returns, or on the relationship between ESG metrics from different data providers. We adopt a different perspective and focus on the relationship between ESG scores and carbon intensity. We ask whether investors face a trade-off when combining carbon objectives and objectives on ESG scores in the construction of their equity portfolio.

More specifically, we quantify the loss of greenness investors incur when they add ESG scores to a low carbon intensity objective in equity portfolios. In particular, we assess portfolios in developed equity markets that use ratings on 25 different ESG themes from three major data providers together with carbon intensity data to make weighting decisions on stocks in the portfolio.

We document large levels of green dilution, that is, the inclusion of ESG scores partly offsets the carbon reduction that is attainable in this universe. Green dilution amounts to 92% on average across 78 different combinations of ESG theme scores. Adding even a single ESG score to a carbon reduction objective leads to green dilution of 65%. Substantial deterioration in green performance also occurs when adding scores for environmental themes, while social or governance themes frequently result in portfolios that are more carbon intensive than the cap-weighted index, i.e. green dilution in excess of 100%. Green dilution is explained by the very low correlation between carbon intensity and ESG scores, which makes portfolio weights drift far from levels that would ensure carbon reduction as soon as weights are partly determined by ESG scores.

While we observe severe green dilution levels for strategies that mix ESG scores with carbon intensity into a composite weighting criterion, we also show that such dilution can be avoided in a straightforward fashion. We show that strategies with ESG exclusions, that first screen out stocks with the lowest ESG scores, and then weight the remaining universe by carbon intensity, do not suffer from green dilution. Since there is effectively no correlation between carbon intensity and ESG scores, removing stocks by ESG scores does not significantly alter the carbon intensity distribution of the stock universe. Applying weights based on carbon intensity to a screened universe thus maintains the high levels of greenness that are attainable without screening.

The difference in green dilution between the mixing and the screening approaches also provides an illustration of how investors can deal with multiple, conflicting objectives. Green dilution can indeed be avoided by establishing carbon reduction as a primary objective via direct inclusion in weighting schemes, while including ESG as a secondary objective via exclusions. Trying to fulfil these two objectives at once, without a clear hierarchy, results in an undesirable outcome, as shown by the strong green dilution of the mixing approach. Such undesirable outcomes are well known in the literature on multiple-objective optimisation[22] but have so far been largely ignored in the ESG literature, where investors are presented with portfolios incorporating a growing number of criteria.

Overall, we provide evidence on the trade-off that investors face when combining climate objectives with information from ESG ratings. We document severe dilution of climate objectives for strategies

22 - See Footnote 7 above.

6. Conclusion

that mix carbon scores and ESG scores as weight determinants. This dilution can be avoided through a separation approach, where ESG scores are used only for screening while weights are solely determined by carbon metrics. This conclusion arises naturally from the fact that ESG ratings and carbon intensity metrics are unrelated to each other. Our conclusions are robust across different ESG ratings providers, different carbon metrics and emission scopes, and different portfolio weighting schemes.

Appendix

Appendix

Appendix 1: ESG Score Coverage Expansion Procedure

Our ESG score data runs from December 2013 to December 2019 (monthly data for MSCI, annual data for Refinitiv, quarterly data for Moody's). Several themes have coverage below 70% of the Scientific Beta developed universe by number of stocks for one or several reporting dates (see Appendix 2 for coverage by ESG theme), and the coverage for several themes is almost mutually exclusive depending on which sectors are considered. Unbalanced ESG score coverage could create unwarranted biases in portfolios, which is why we use a score coverage expansion procedure in three steps.

- **Step 1:** Time-series interpolation. If a company has gaps in the time series of a pillar score (E, S, or G) or theme score, we can fill in the gaps via linear interpolation through time (months for MSCI data, years for Refinitiv data, quarters for Moody's data). E.g., we have no scores for the MSCI theme Climate Change for Company A between March 2014 and February 2015 but we have scores before and after. Scores between these two dates will be interpolated linearly.

- **Step 2:** Carry over theme and pillar scores for one year. When a data provider stops reporting a pillar or theme score for a company, we can carry over the previous score for one year. This carryover takes advantage of the fact that there is typically little change in ESG scores from one year to another, unlike changes over several years, which can be more significant. E.g., we have E, S, and G scores from Refinitiv for company B until December 2017, we can use these scores for company B until December 2018 but not from December 2019.

- **Step 3:** Approximating theme scores based on pillar scores. We only perform this step for theme scores with raw coverage below 70% but above 20% at any point in time[23]. At each reporting date, we use cross-sectional regressions of theme scores on their corresponding pillar scores (E or S or G), which have better coverage (above 90%). The correlation of themes to their corresponding pillar is strong, allowing for reasonable theme score expansion. E.g., Company C has a MSCI E score in December 2014 but no Environmental Opportunities score. We run a regression of MSCI Environmental Opportunities scores on MSCI E scores using all stocks with datapoints for both on that date, and obtain an approximated Environmental Opportunities scores based on the fitted value from that cross-sectional regression for company C.

Appendix 2: Developed Universe Coverage of ESG Scores, before and after Coverage Expansion

The below charts show the coverage percentage (share of stocks in the scientific beta developed universe with ESG theme score) for each theme score over time, before and after running the coverage expansion procedure presented in Appendix 1.

23 - This group of scores includes the following MSCI themes: Waste Management, Environmental Opportunities, Social Opportunities, Product Safety, and Business Ethics, and the following Refinitiv themes: CSR Strategy, Human Rights, and Environmental Innovation. This third step is not used for Moody's scores since they do not have corresponding pillar scores. The MSCI theme Stakeholder Opposition has a coverage that is too low to be expanded (close to 5%), we therefore exclude it from our list of themes when building portfolios.

Appendix

Figure A1. Coverage of MSCI ESG Theme Scores Before Coverage Expansion

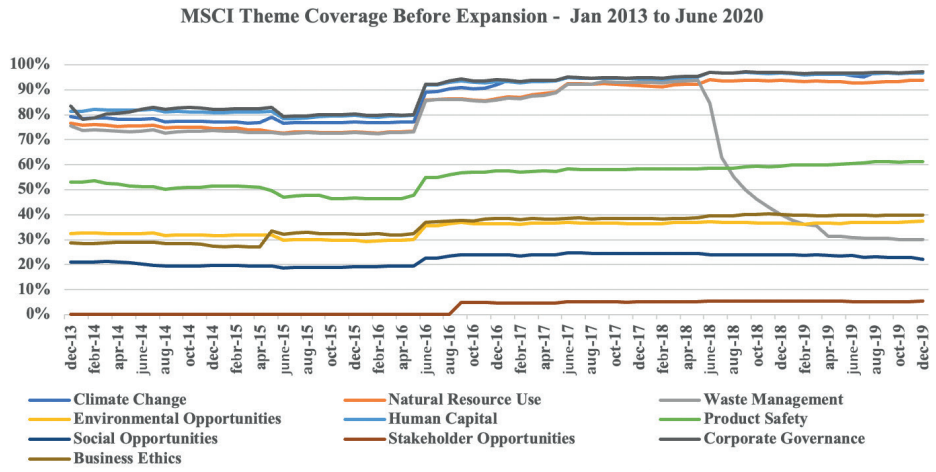


Figure A2. Coverage of MSCI ESG Theme Scores After Coverage Expansion

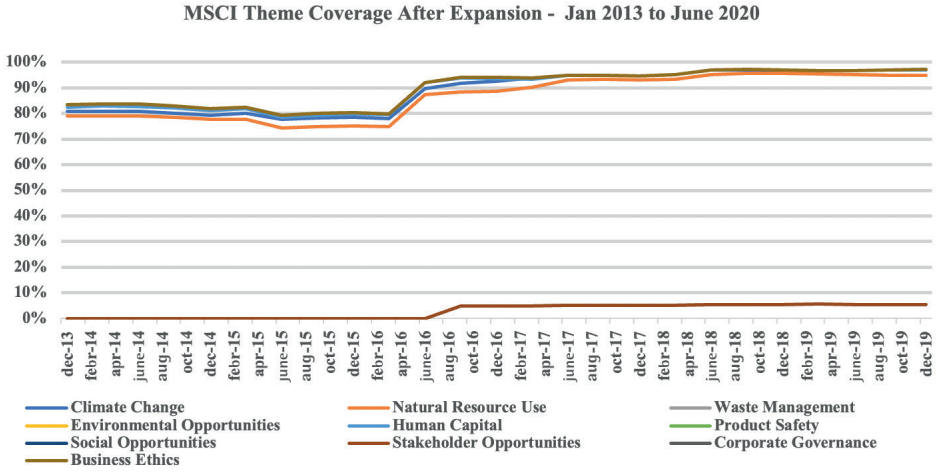
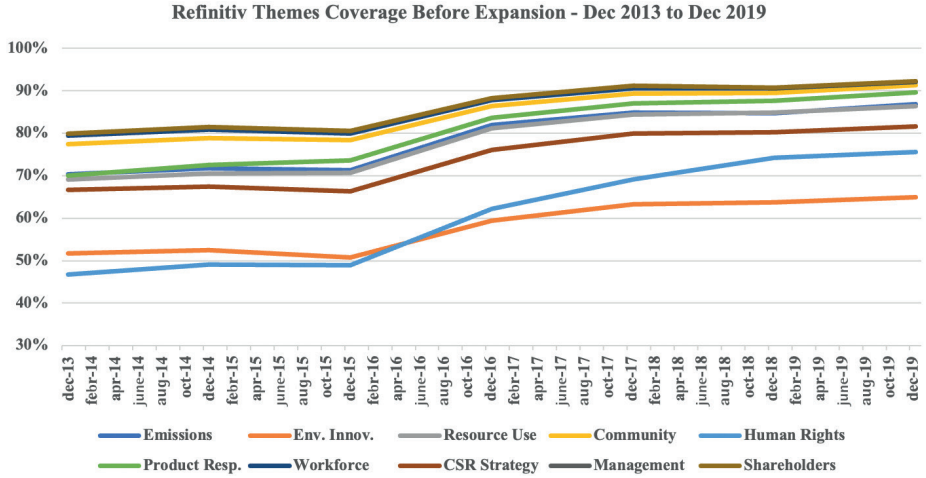


Figure A3. Coverage of Refinitiv ESG Theme Scores Before Coverage Expansion



Appendix

Figure A4. Coverage of Refinitiv ESG Theme Scores After Coverage Expansion

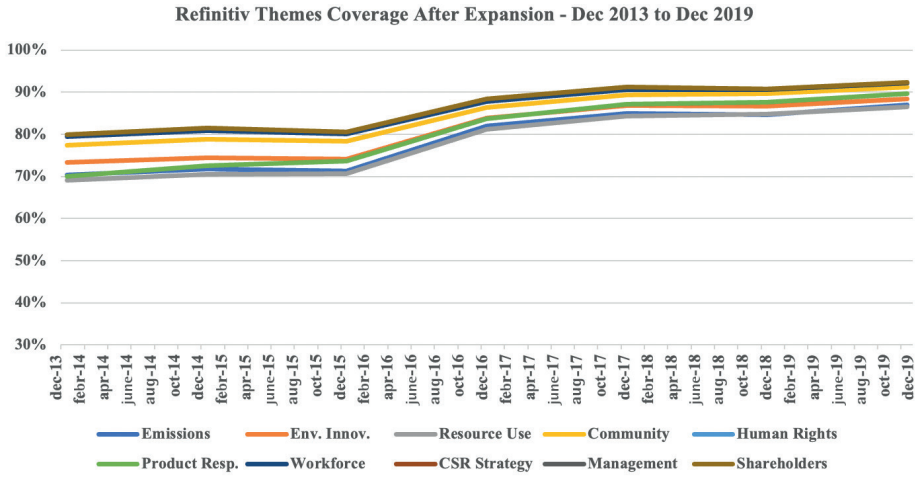


Figure A5. Coverage of Moody's ESG Theme Scores Before Coverage Expansion

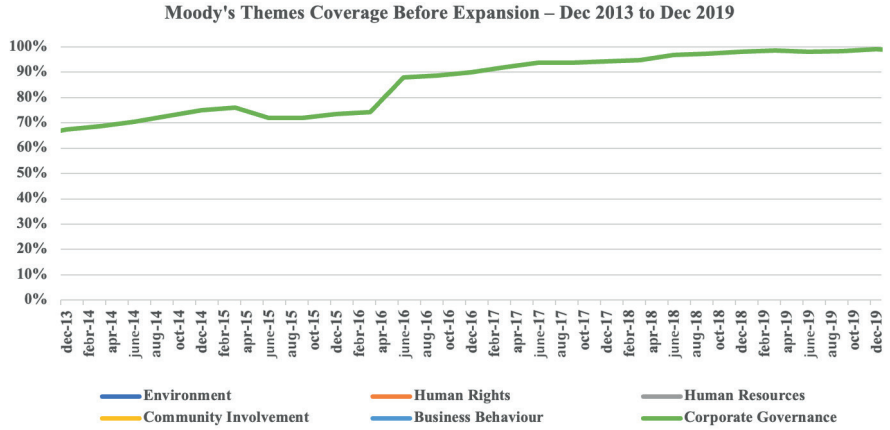
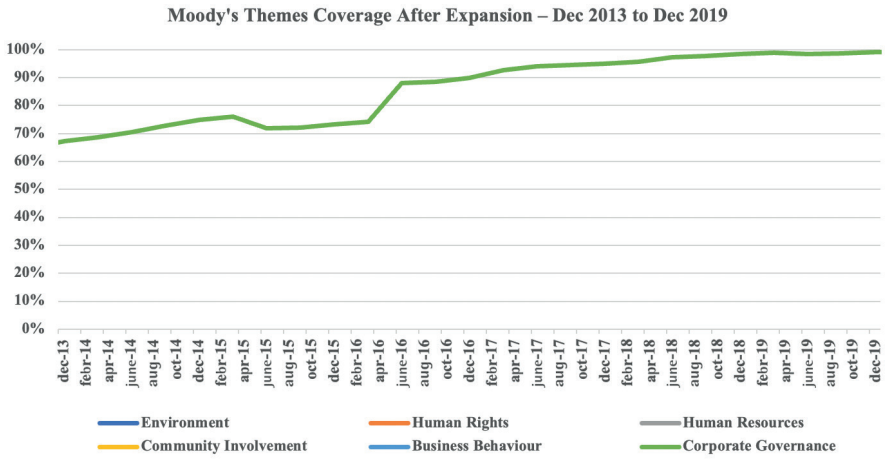


Figure A6. Coverage of Moody's ESG Theme Scores After Coverage Expansion

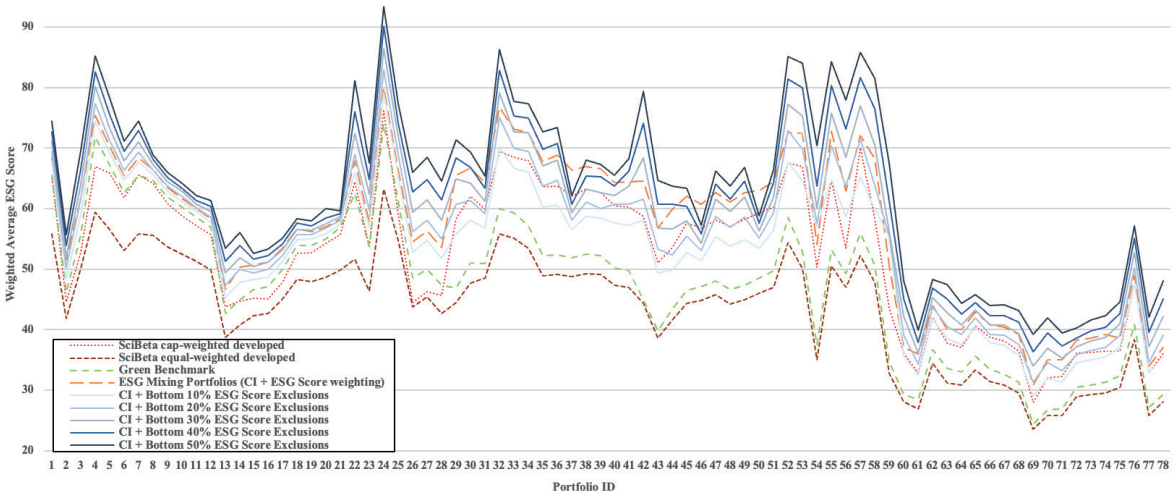


Note: the series for each Moody's theme are indistinguishable since Equitics coverage is done on a stock-level basis with either all theme scores or no theme scores available.

Appendix

Appendix 3: Portfolio-level weighted average ESG Scores

Figure A7. Weighted Average ESG Score of Multiple-Objectives Portfolios



The above chart shows the average ESG scores for our 78 combinations of ESG theme scores, calculated only across the ESG scores that are considered in each portfolio, averaged across years from December 2013 to December 2019. The list of ESG themes included in each portfolio and corresponding portfolio IDs are available in Appendix 4. MSCI ESG theme scores were multiplied by 10 to match the scale of Refinitiv and Moody's scores.

ESG Mixing portfolios reach ESG scores consistent with an exclusion of the bottom 20% to 30% stocks by average ESG scores. Equal weights result in the least ESG-friendly portfolios, and the green benchmark is usually the second worst portfolio by average ESG score. Portfolios with stock weights based on carbon intensity and ESG screening exclusion above 20% usually have better ESG scores than the cap-weighted index and the green benchmark, for a green performance close to the green benchmark.

Using MSCI ESG ratings (portfolio IDs 1 to 28 as indicated in Appendix 4.) results in more ESG-friendly green portfolios: the ESG scores of the green benchmark are closer to the ESG scores of ESG screening portfolios with MSCI than with other ESG rating providers (Portfolio IDs 29 to 78).

Appendix

Appendix 4: List of 78 ESG Theme Score Combinations

Table A1. List of All 78 ESG Theme Score Combinations

Portfolio ID	Portfolio Group	ESG Rating Provider	Portfolio weight determinants (Carbon Intensity and ESG themes)
1	2	MSCI	CI + Climate Change + Natural Res Use + Waste Mgmt + Env. Opps
2	2	MSCI	CI + Human Capital + Product Safety + Social Opps
3	2	MSCI	CI + Corporate Gov + Business Ethics
4	1	MSCI	CI + Waste Mgmt
5	3	MSCI	CI + Waste Mgmt + Natural Res Use
6	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps
7	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps + Climate Change
8	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps + Climate Change + Corporate Gov
9	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps + Climate Change + Corporate Gov + Product Safety
10	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps + Climate Change + Corporate Gov + Product Safety + Business Ethics
11	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps + Climate Change + Corporate Gov + Product Safety + Business Ethics + Human Capital
12	3	MSCI	CI + Waste Mgmt + Natural Res Use + Env. Opps + Climate Change + Corporate Gov + Product Safety + Business Ethics + Human Capital + Social Opps
13	1	MSCI	CI + Social Opps
14	3	MSCI	CI + Social Opps + Human Capital
15	3	MSCI	CI + Social Opps + Human Capital + Business Ethics
16	3	MSCI	CI + Social Opps + Human Capital + Business Ethics + Product Safety
17	3	MSCI	CI + Social Opps + Human Capital + Business Ethics + Product Safety + Corporate Gov
18	3	MSCI	CI + Social Opps + Human Capital + Business Ethics + Product Safety + Corporate Gov + Climate Change
19	3	MSCI	CI + Social Opps + Human Capital + Business Ethics + Product Safety + Corporate Gov + Climate Change + Env. Opps
20	3	MSCI	CI + Social Opps + Human Capital + Business Ethics + Product Safety + Corporate Gov + Climate Change + Env. Opps + Natural Res Use
21	3	MSCI	CI + Social Opps + Human Capital + Business Ethics + Product Safety + Corporate Gov + Climate Change + Env. Opps + Natural Res Use + Waste Mgmt
22	1	MSCI	CI + Natural Res Use
23	1	MSCI	CI + Env. Opps
24	1	MSCI	CI + Climate Change
25	1	MSCI	CI + Corporate Gov
26	1	MSCI	CI + Product Safety
27	1	MSCI	CI + Business Ethics
28	1	MSCI	CI + Human Capital
29	2	Refinitiv	CI + Emissions + Env. Innov. + Resource Use
30	2	Refinitiv	CI + Community + Human Rights + Product Resp. + Workforce
31	2	Refinitiv	CI + CSR Strategy + Mgmt. + Shareholders
32	1	Refinitiv	CI + Workforce
33	3	Refinitiv	CI + Workforce + Mgmt.
34	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use
35	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights

Appendix

36	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights + Emissions
37	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights + Emissions + Shareholders
38	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights + Emissions + Shareholders + Community
39	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights + Emissions + Shareholders + Community + Product Resp.
40	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights + Emissions + Shareholders + Community + Product Resp. + Env. Innov.
41	3	Refinitiv	CI + Workforce + Mgmt. + Resource Use + Human Rights + Emissions + Shareholders + Community + Product Resp. + Env. Innov. + CSR Strategy
42	1	Refinitiv	CI + CSR Strategy
43	3	Refinitiv	CI + CSR Strategy + Env. Innov.
44	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp.
45	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community
46	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community + Shareholders
47	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community + Shareholders + Emissions
48	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community + Shareholders + Emissions + Human Rights
49	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community + Shareholders + Emissions + Human Rights + Resource Use
50	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community + Shareholders + Emissions + Human Rights + Resource Use + Mgmt.
51	3	Refinitiv	CI + CSR Strategy + Env. Innov. + Product Resp. + Community + Shareholders + Emissions + Human Rights + Resource Use + Mgmt. + Workforce
52	1	Refinitiv	CI + Mgmt.
53	1	Refinitiv	CI + Resource Use
54	1	Refinitiv	CI + Human Rights
55	1	Refinitiv	CI + Emissions
56	1	Refinitiv	CI + Shareholders
57	1	Refinitiv	CI + Community
58	1	Refinitiv	CI + Product Resp.
59	1	Refinitiv	CI + Env. Innov.
60	2	Moody's	CI + Environment
61	2	Moody's	CI + Human Rights + Human Resources + Community Involvement
62	2	Moody's	CI + Business Behaviour + Corporate Governance
63	1	Moody's	CI + Human Rights
64	3	Moody's	CI + Human Rights + Business Behaviour
65	3	Moody's	CI + Human Rights + Business Behaviour + Corporate Governance
66	3	Moody's	CI + Human Rights + Business Behaviour + Corporate Governance + Community Involvement
67	3	Moody's	CI + Human Rights + Business Behaviour + Corporate Governance + Community Involvement + Environment
68	3	Moody's	CI + Human Rights + Business Behaviour + Corporate Governance + Community Involvement + Environment + Human Resources
69	1	Moody's	CI + Human Resources
70	3	Moody's	CI + Human Resources + Environment
71	3	Moody's	CI + Human Resources + Environment + Community Involvement
72	3	Moody's	CI + Human Resources + Environment + Community Involvement + Corporate Governance
73	3	Moody's	CI + Human Resources + Environment + Community Involvement + Corporate Governance + Business Behaviour
74	3	Moody's	CI + Human Resources + Environment + Community Involvement + Corporate Governance + Business Behaviour + Human Rights
75	1	Moody's	CI + Business Behaviour
76	1	Moody's	CI + Corporate Governance
77	1	Moody's	CI + Community Involvement
78	1	Moody's	CI + Environment

Appendix

Appendix 5: Construction Methodology for Optimised Portfolios

Our ESG and carbon mixing portfolios provide a clear illustration of the loss of greenness investors face when adding ESG scores to carbon intensity using stylised, rank-weighted portfolios. In practice, systematic ESG strategies can be based on optimisation, targeting a level of ESG score improvement while limiting deviations relative to a cap-weighted benchmark. Optimised portfolios offer a practical complement to rank-weighted portfolios and will allow us to test our findings using a different weighting scheme. The procedure for testing green dilution remains the same as with rank-weighted portfolios, only the weighting scheme differs. We therefore first construct an optimised green benchmark, and subsequently build optimised ESG and carbon mixing portfolios. Comparing the green performance of optimised ESG and carbon mixing portfolios over the cap-weighted index to the green performance of the optimised green benchmark, we can quantify green dilution in optimised portfolios.

The optimised green benchmark

Our optimised green benchmark is constructed as follows. The objective function we minimise is the negative of the weighted average of carbon intensity ranks:

$$\min_{w^{i,gb}_{Optimised,t}} \; -\sum_{i\in All_t} w^{i,gb}_{Optimised,t} \times CI\downarrow Rank^i_t$$

$w^{i,gb}_{Optimised,t}$ is the weight of stock *i* in the optimised green benchmark at year end *t*, $CI\downarrow Rank^i_t$ is the descending rank of stock *i* by Scope 1+2 Carbon Intensity. All_t is the Scientific Beta developed universe of stocks with both carbon intensity and ESG scores at year end *t*. We use ranks to allow for a smoother optimisation problem since the distribution of carbon intensities is very irregular. Ranks will also allow us to easily combine variables with different distributions (carbon intensities and ESG scores from different providers) to build optimised ESG mixing portfolios. Note that we only use ranks in optimised portfolios as a way to harmonise distributions and not as a weighting scheme. We impose three constraints to this objective function:

1. Budget constraint. Weights sum to one, and no short selling: $\sum_{i\in All_t} w^i_t = 1$ *and* $w^i_t \geq 0$ for *all* $i \in All_t$
2. The lower (upper) bound for weights will be set to the minimum (maximum) weight of the rank-weighted green benchmark, which is the green benchmark in our base specification. This is to ensure similar diversification is maintained across rank-weighted and optimised green benchmarks: $min\,(w^{i,gb}_{Optimized,t}) = min(w^{i,gb}_{Rank,t})$ and $max\,(w^{i,gb}_{Optimised,t}) = max(w^{i,gb}_{Rank,t})$
3. The tracking error of the optimised green benchmark relative to the cap-weighted index must be inferior or equal to that of the rank-weighted green benchmark, to ensure performance comparability between rank-weighted and optimised green benchmarks: $TE^{gb}_{Optimized,t} \leq TE^{gb}_{Rank,t}$.

Tracking error is estimated based on two years of weekly returns at each annual rebalancing date. The variance-covariance matrix used in the tracking error calculation is shrunk using Principal Component Analysis (PCA) following the approach of Coqueret and Milhau (2014).

The optimised ESG and carbon mixing portfolios

Optimised ESG and carbon mixing portfolios are built in a similar way to the optimised green benchmark, but adding combinations of ESG scores to carbon intensity in the weighing scheme.

Appendix

Optimised ESG and carbon mixing portfolios have stock weights determined by the following optimisation problem, using an average cross-sectional rank of carbon intensity and ESG scores, instead of carbon intensity ranks only in the case of the green benchmark. The objective function is the negative of the weighted average rank of the portfolio:

$$\min_{w^{i,\,Mixing\ x}_{Optimised,t}} \left(-\sum_{i \in All_t} w^{i,\,Mixing\ x}_{Optimised,t} \times \frac{CI{\downarrow}Rank_i + ESG{\uparrow}Rank_i^{theme\ 1} + ESG{\uparrow}Rank_i^{theme\ 2} + \cdots + ESG{\uparrow}Rank_i^{theme\ T}}{T+1} \right)$$

$w^{i,Mixing\ x}_{Optimised,t}$ is the weight of stock *i* in an optimised portfolio for a given combination of ESG scores x at year end t, $CI \downarrow Rank_t^i$ is the descending rank of stock *i* by Scope 1+2 Carbon Intensity, $ESG \uparrow Rank_i^{theme\ T}$ the ascending rank of stock i for ESG theme *T*. All_t is the Scientific Beta developed universe of stocks with both carbon intensity and ESG scores at year end *t*. Using ranks makes the optimisation problem smoother, allowing us to combine carbon intensities and ESG scores from different providers despite differences in their respective distributions. We impose three constraints to this objective function:

1. Budget constraint. Weights sum to one and no short selling: $\sum_{i \in All_t} w_t^i = 1\ and\ w_t^i \geq 0$ for *all* $i \in All_t$
2. The lower (upper) bound for portfolio weights will be set to the minimum (maximum) weight of the corresponding rank-weighted portfolio, which is the portfolio built using carbon intensity and the same ESG scores, but with the rank-based weighting scheme used in our base specification. This is to ensure similar diversification is maintained across rank-weighted and optimised portfolios built using the same scores. For a given combination of carbon intensity and ESG scores *x*, we impose:

$$min\ (w^{i,\,Mixing\ x}_{Optimised,\,t}) = min(w^{i,\,Mixing\ x}_{Rank,\,t}) \text{ and } max\ (w^{i,\,Mixing\ x}_{Optimised,\,t}) = max(w^{i,\,Mixing\ x}_{Rank,\,t})$$

3. The tracking error of optimised portfolios relative to the cap-weighted index must be inferior or equal to that of the corresponding rank-weighted portfolio to ensure performance comparability across rank-weighted and optimised portfolios: $TE^{Portfolio\ x}_{Optimised,\,t} \leq TE^{Portfolio\ x}_{Rank\ based,\,t}$. The variance-covariance matrix used in the tracking error calculation is shrunk using Principal Component Analysis (PCA) following the approach of Coqueret and Milhau (2014).

We use the same three portfolio groups we defined for rank-weighted portfolios for optimised portfolios (group 1 mixes a single ESG theme with carbon intensity, group 2 mixes all themes in a given pillar — E, S or G — per provider with carbon intensity, and group 3 mixes cumulative combinations of ESG themes with carbon intensity, selected by their correlation with carbon intensity). This gives us a total of 78 optimised ESG and carbon mixing portfolios, on top of the existing 78 rank-weighted ESG and carbon mixing portfolios portfolios. Detailed greenness and green dilution results for these three groups can be found in our online supplement.

Appendix 6. Construction Methodology for Portfolios Controlling for Different Numbers of Scores Across ESG Ratings Providers

The portfolios comprising our three groups can have their carbon objectives diluted by a varying number of scores. For instance, the cumulative combination of ESG scores will reach a total of 10

Appendix

scores using Refintiv data but 6 scores for Moody's. To control for the varying numbers of ESG scores per provider, we compute greenness and dilution for portfolios including the same number of ESG scores across our three ESG data providers. These robustness portfolios include three groups:

- **Group 1**: our 25 single-scores portfolios, which do not suffer from a varying number of scores, since each portfolio is based on a single score from each provider and carbon intensity. This group 1 is identical to the group 1 of our base specification.
- **Group 4**: portfolios built with the cumulative addition of ESG scores from greenest to brownest (lowest to highest correlation of scores to carbon intensity) but stopping at 6 scores maximum. Our provider with the fewest theme scores is Moody's with 6 scores, so for each provider we compute portfolios using 5 cumulative combinations of scores (from 2 to 6 scores), resulting in 5*3 = 15 portfolios.
- **Group 5**: portfolios built with the cumulative addition of ESG scores from brownest to greenest (highest to lowest correlation of scores to carbon intensity), but stopping at 6 scores maximum, also resulting in 5*3 = 15 portfolios.

Detailed greenness and green dilution results for these three groups of portfolios can be found in our online supplement.

Online Supplement

Table S1. Scope 1+2 Greenness and Green Dilution of Individual Rank-Weighted ESG and Carbon Mixing Portfolios (Base Specification)

Portfolio ID	Portfolio Group	ESG Ratings Provider	Average Scope 1+2 WACI	Green Dilution based on Average Scope 1+2 WACI	Carbon Sensitivity	t-stat of Carbon Sensitivity	Green Dilution based on Carbon Sensitivity
1	2	MSCI	153	71.0%	-8.1	-66.1	74.2%
2	2	MSCI	213	110.2%	-4.2	-33.0	99.6%
3	2	MSCI	200	101.9%	-6.4	-48.7	85.3%
4	1	MSCI	91	31.0%	-14.1	-111.5	35.5%
5	3	MSCI	126	53.4%	-10.9	-88.5	55.9%
6	3	MSCI	144	65.6%	-9.2	-75.8	67.1%
7	3	MSCI	153	71.0%	-8.1	-66.1	74.2%
8	3	MSCI	172	83.7%	-6.8	-62.8	82.4%
9	3	MSCI	186	92.5%	-5.8	-58.6	89.0%
10	3	MSCI	198	100.8%	-5.0	-52.1	94.4%
11	3	MSCI	206	106.2%	-4.3	-47.0	98.9%
12	3	MSCI	213	110.1%	-3.7	-40.7	102.5%
13	1	MSCI	155	72.9%	-9.1	-80.6	67.6%
14	3	MSCI	194	98.3%	-5.7	-46.4	90.0%
15	3	MSCI	218	113.4%	-4.0	-38.3	100.5%
16	3	MSCI	228	119.9%	-3.2	-28.8	106.1%
17	3	MSCI	234	124.4%	-2.7	-25.5	109.0%
18	3	MSCI	227	119.8%	-2.9	-29.3	108.1%

Appendix

19	3	MSCI	224	117.6%	-3.0	-31.6	107.2%
20	3	MSCI	221	115.5%	-3.2	-34.2	106.0%
21	3	MSCI	213	110.1%	-3.7	-40.7	102.5%
22	1	MSCI	119	49.2%	-12.1	-96.8	48.3%
23	1	MSCI	122	51.1%	-11.8	-95.0	50.3%
24	1	MSCI	115	46.3%	-11.6	-88.9	51.2%
25	1	MSCI	156	73.4%	-10.0	-80.5	61.9%
26	1	MSCI	155	73.0%	-9.6	-84.0	64.1%
27	1	MSCI	165	79.5%	-9.3	-78.7	66.1%
28	1	MSCI	158	74.5%	-9.1	-79.2	67.4%
29	2	Refinitiv	222	116.1%	-5.3	-34.8	92.4%
30	2	Refinitiv	212	109.5%	-4.8	-33.2	95.4%
31	2	Refinitiv	236	125.4%	-4.8	-36.7	95.9%
32	1	Refinitiv	140	62.9%	-12.3	-88.0	46.7%
33	3	Refinitiv	187	93.3%	-8.3	-58.6	73.2%
34	3	Refinitiv	208	107.2%	-6.2	-43.5	86.7%
35	3	Refinitiv	214	111.0%	-5.1	-35.1	93.6%
36	3	Refinitiv	227	119.2%	-4.2	-27.7	99.8%
37	3	Refinitiv	238	127.0%	-3.4	-24.8	104.9%
38	3	Refinitiv	245	131.3%	-2.8	-20.7	108.4%
39	3	Refinitiv	246	131.7%	-2.5	-18.3	110.7%
40	3	Refinitiv	249	133.8%	-2.1	-15.9	113.0%
41	3	Refinitiv	254	137.3%	-1.7	-12.6	115.8%
42	1	Refinitiv	177	86.9%	-10.2	-75.9	60.8%
43	3	Refinitiv	211	109.0%	-6.4	-47.1	85.1%
44	3	Refinitiv	221	115.3%	-4.7	-34.9	96.2%
45	3	Refinitiv	235	124.5%	-3.6	-26.8	103.6%
46	3	Refinitiv	247	132.8%	-2.8	-22.5	108.9%
47	3	Refinitiv	253	136.7%	-2.3	-17.9	112.0%
48	3	Refinitiv	251	135.4%	-2.1	-16.2	113.1%
49	3	Refinitiv	254	136.9%	-1.9	-13.7	114.7%
50	3	Refinitiv	256	138.6%	-1.7	-12.9	115.9%
51	3	Refinitiv	254	137.3%	-1.7	-12.6	115.8%
52	1	Refinitiv	163	78.0%	-11.5	-76.1	52.0%
53	1	Refinitiv	159	75.4%	-11.4	-82.1	52.6%
54	1	Refinitiv	142	64.0%	-11.9	-88.9	49.4%
55	1	Refinitiv	168	81.2%	-11.2	-82.4	54.2%
56	1	Refinitiv	178	87.9%	-10.8	-74.9	56.7%
57	1	Refinitiv	169	81.6%	-11.0	-74.9	55.3%
58	1	Refinitiv	148	68.2%	-11.3	-80.6	53.7%
59	1	Refinitiv	162	77.5%	-10.9	-77.6	55.7%
60	2	Moody's	162	76.9%	-8.7	-76.6	70.6%
61	2	Moody's	220	114.8%	-3.5	-25.2	104.2%
62	2	Moody's	207	106.3%	-5.5	-42.7	91.2%

Appendix

63	1	Moody's	155	72.7%	-9.5	-79.1	64.9%
64	3	Moody's	199	101.5%	-5.9	-43.2	88.8%
65	3	Moody's	222	116.3%	-3.9	-29.7	101.2%
66	3	Moody's	233	123.7%	-2.7	-20.0	109.1%
67	3	Moody's	241	128.8%	-1.9	-13.6	114.6%
68	3	Moody's	248	133.3%	-1.2	-8.3	119.1%
69	1	Moody's	166	79.8%	-8.4	-72.7	72.4%
70	3	Moody's	204	104.6%	-4.8	-37.3	95.7%
71	3	Moody's	223	116.9%	-3.0	-22.5	107.0%
72	3	Moody's	236	125.6%	-2.1	-15.9	113.2%
73	3	Moody's	245	131.2%	-1.5	-10.8	117.1%
74	3	Moody's	248	133.3%	-1.2	-8.3	119.1%
75	1	Moody's	165	79.3%	-9.1	-72.3	67.7%
76	1	Moody's	166	79.9%	-9.0	-73.7	68.6%
77	1	Moody's	161	76.6%	-8.8	-73.4	69.9%
78	1	Moody's	162	76.9%	-8.7	-76.6	70.6%
Average	**All**	**All**	**196**	**99.1%**	**-6.4**	**-50.6**	**85.4%**

Note: the list of ESG themes corresponding to each portfolio ID can be found in Appendix 4. This table reports average WACI and carbon sensitivity of weights for our 78 rank-weighted ESG and carbon mixing portfolios. T-stats are heteroskedasticity adjusted following White (1980). Carbon sensitivity is estimated from the following pooled regression run separately for each portfolio: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. *Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability.* w_t^i *is the weight of stock i at rebalancing date t,* CI_t^i *its carbon intensity. Using the same notation, average WACI is computed as (WACI)* $\overline{WACI} = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{N}(w_t^i CI_t^i))}{T}$, *with t running from Dec 2013 to Dec 2019 and T =7. The average is computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 21 (all MSCI themes are also in portfolio 12), 51 (all Refinitiv themes are also in portfolio 41), 74 (all Moody's themes are also in portfolio 68), and 78 (Moody's lone Environmental score is also in portfolio 60).*

Table S2. Scope 1+2 Greenness and Green Dilution of Individual Optimised ESG and Carbon Mixing Portfolios (Robustness Test)

Portfolio ID	Portfolio Group	ESG Rating Provider	Average Scope 1+2 WACI	Green Dilution based on Average Scope 1+2 WACI	Carbon Sensitivity	t-stat of Carbon Sensitivity	Green Dilution based on Carbon Sensitivity
1	2	MSCI	62	26.4%	-15.4	-63.1	50.4%
2	2	MSCI	185	93.4%	-8.1	-26.8	82.7%
3	2	MSCI	158	78.9%	-11.2	-37.6	69.0%
4	1	MSCI	30	9.1%	-22.1	-107.4	21.1%
5	3	MSCI	45	17.6%	-19.3	-84.1	33.2%
6	3	MSCI	59	24.8%	-17.1	-74.6	43.2%
7	3	MSCI	62	26.4%	-15.4	-63.1	50.4%
8	3	MSCI	81	36.9%	-14.3	-61.8	55.4%
9	3	MSCI	102	48.3%	-12.6	-53.7	62.9%
10	3	MSCI	118	56.8%	-11.3	-47.1	68.4%
11	3	MSCI	135	66.3%	-9.9	-41.1	74.7%
12	3	MSCI	155	77.4%	-8.6	-34.8	80.4%
13	1	MSCI	57	24.1%	-17.9	-83.7	39.6%
14	3	MSCI	156	77.9%	-10.2	-35.1	73.4%
15	3	MSCI	185	93.4%	-8.5	-30.0	81.0%
16	3	MSCI	204	104.1%	-6.9	-23.7	87.9%
17	3	MSCI	215	109.6%	-6.2	-21.1	90.9%

Appendix

18	3	MSCI	198	100.6%	-6.3	-22.6	90.4%
19	3	MSCI	188	95.3%	-6.9	-25.7	88.0%
20	3	MSCI	177	89.2%	-7.2	-27.8	86.4%
21	3	MSCI	155	77.4%	-8.6	-34.8	80.4%
22	1	MSCI	31	9.5%	-21.4	-101.3	24.1%
23	1	MSCI	38	13.4%	-20.5	-100.1	28.1%
24	1	MSCI	31	10.0%	-20.3	-104.1	28.7%
25	1	MSCI	53	21.8%	-18.9	-89.9	34.9%
26	1	MSCI	59	25.1%	-18.6	-87.6	36.5%
27	1	MSCI	53	21.9%	-18.4	-88.0	37.4%
28	1	MSCI	68	30.1%	-17.5	-80.1	41.0%
29	2	Refinitiv	174	87.6%	-9.5	-25.0	76.3%
30	2	Refinitiv	152	75.7%	-9.2	-25.1	77.5%
31	2	Refinitiv	194	98.5%	-10.0	-27.9	74.4%
32	1	Refinitiv	50	20.3%	-22.9	-90.2	17.4%
33	3	Refinitiv	107	51.1%	-16.5	-51.2	45.6%
34	3	Refinitiv	141	69.7%	-11.5	-32.7	67.7%
35	3	Refinitiv	157	78.0%	-9.1	-25.1	77.9%
36	3	Refinitiv	179	90.3%	-7.1	-19.3	87.0%
37	3	Refinitiv	203	103.2%	-6.0	-16.7	91.8%
38	3	Refinitiv	226	115.5%	-5.0	-13.7	96.2%
39	3	Refinitiv	219	112.0%	-4.2	-11.7	99.8%
40	3	Refinitiv	229	117.4%	-3.4	-9.8	103.0%
41	3	Refinitiv	238	122.4%	-2.6	-7.4	106.8%
42	1	Refinitiv	69	30.5%	-19.8	-74.4	31.0%
43	3	Refinitiv	153	76.3%	-11.9	-34.3	65.9%
44	3	Refinitiv	183	92.5%	-8.4	-23.6	81.2%
45	3	Refinitiv	201	102.0%	-6.3	-18.5	90.6%
46	3	Refinitiv	218	111.2%	-5.3	-16.1	95.0%
47	3	Refinitiv	229	117.6%	-4.1	-12.4	99.9%
48	3	Refinitiv	227	116.4%	-3.5	-10.3	102.7%
49	3	Refinitiv	234	120.3%	-2.9	-8.4	105.2%
50	3	Refinitiv	240	123.5%	-2.5	-7.4	107.0%
51	3	Refinitiv	238	122.4%	-2.6	-7.4	106.8%
52	1	Refinitiv	61	26.0%	-22.2	-83.2	20.5%
53	1	Refinitiv	52	21.3%	-22.4	-86.5	19.5%
54	1	Refinitiv	52	21.3%	-21.9	-86.3	21.7%
55	1	Refinitiv	59	24.7%	-22.4	-86.0	19.7%
56	1	Refinitiv	69	30.6%	-21.4	-80.4	24.2%
57	1	Refinitiv	60	25.4%	-21.7	-81.2	22.9%
58	1	Refinitiv	48	19.0%	-21.9	-86.8	22.0%
59	1	Refinitiv	56	23.6%	-21.7	-81.8	22.8%
60	2	Moody's	62	26.6%	-18.0	-87.5	39.0%
61	2	Moody's	199	101.0%	-4.9	-15.0	96.5%

Appendix

62	2	Moody's	167	83.9%	-10.4	-33.3	72.5%
63	1	Moody's	55	22.8%	-19.3	-85.6	33.4%
64	3	Moody's	166	83.2%	-9.6	-30.7	76.1%
65	3	Moody's	206	104.8%	-6.8	-21.3	88.3%
66	3	Moody's	229	117.6%	-4.1	-12.7	100.1%
67	3	Moody's	247	127.4%	-2.3	-7.1	108.0%
68	3	Moody's	256	131.9%	-1.1	-3.4	113.4%
69	1	Moody's	54	22.4%	-18.8	-84.4	35.6%
70	3	Moody's	162	81.0%	-7.8	-24.8	83.9%
71	3	Moody's	207	105.7%	-3.9	-11.9	100.9%
72	3	Moody's	238	122.5%	-2.3	-7.2	107.9%
73	3	Moody's	251	129.2%	-1.6	-4.9	111.2%
74	3	Moody's	256	131.9%	-1.1	-3.4	113.4%
75	1	Moody's	71	31.5%	-17.8	-75.4	40.0%
76	1	Moody's	63	27.3%	-18.2	-79.3	38.1%
77	1	Moody's	60	25.7%	-18.2	-77.4	38.3%
78	1	Moody's	62	26.6%	-18.0	-87.5	39.0%
Average	**All**	**All**	**136**	**67.0%**	**-12.1**	**-47.4**	**65.1%**

Note: the list of ESG themes corresponding to each portfolio ID can be found in Appendix 4. This table reports average WACI and carbon sensitivity of weights for our 78 rank-weighted ESG and carbon mixing portfolios. T-stats are heteroskedasticity adjusted following White (1980). Carbon sensitivity is estimated from the following pooled regression run separately for each portfolio: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. *Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability.* w_t^i *is the weight of stock i at rebalancing date t,* CI_t^i *its carbon intensity. Using the same notation, average WACI is computed as* $\overline{WACI} = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{N}(w_t^i CI_t^i))}{T}$, *with t running from Dec 2013 to Dec 2019 and T =7. The average is computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 21 (all MSCI themes are also in portfolio 12), 51 (all Refinitiv themes are also in portfolio 41), 74 (all Moody's themes are also in portfolio 68), and 78 (Moody's lone Environmental score is also in portfolio 60).*

Table S3. Scope 1+2 Greenness and Green Dilution of Individual Rank-weighted ESG and Carbon Mixing Portfolios, Controlling for Different Numbers of ESG Themes across Providers (Robustness Test)

Portfolio ID	Portfolio Group	ESG Ratings Provider	Average Scope 1+2 WACI	Green Dilution based on Average Scope 1+2 WACI	Carbon Sensitivity	t-stat of Carbon Sensitivity	Green Dilution based on Carbon Sensitivity
4	1	MSCI	90	30.1%	-14.1	-111.5	35.5%
5	4	MSCI	123	51.5%	-10.9	-88.5	55.9%
6	4	MSCI	141	63.5%	-9.2	-75.8	67.1%
7	4	MSCI	149	68.8%	-8.1	-66.1	74.2%
8	4	MSCI	168	81.1%	-6.8	-62.8	82.4%
9	4	MSCI	181	89.7%	-5.8	-58.6	89.0%
13	1	MSCI	151	70.3%	-9.1	-80.6	67.6%
14	5	MSCI	190	95.1%	-5.7	-46.4	90.0%
15	5	MSCI	212	109.9%	-4.0	-38.3	100.5%
16	5	MSCI	222	116.1%	-3.2	-28.8	106.1%
17	5	MSCI	229	120.6%	-2.7	-25.5	109.0%
18	5	MSCI	222	116.2%	-2.9	-29.3	108.1%
22	1	MSCI	115	46.8%	-12.1	-96.8	48.3%
23	1	MSCI	119	49.4%	-11.8	-95.0	50.3%
24	1	MSCI	112	44.8%	-11.6	-88.9	51.2%
25	1	MSCI	153	71.1%	-10.0	-80.5	61.9%

Appendix

26	1	MSCI	151	70.2%	-9.6	-84.0	64.1%
27	1	MSCI	161	76.7%	-9.3	-78.7	66.1%
28	1	MSCI	154	72.2%	-9.1	-79.2	67.4%
32	1	Refinitiv	136	60.5%	-12.3	-88.0	46.7%
33	4	Refinitiv	182	90.3%	-8.3	-58.6	73.2%
34	4	Refinitiv	203	103.6%	-6.2	-43.5	86.7%
35	4	Refinitiv	208	107.4%	-5.1	-35.1	93.6%
36	4	Refinitiv	221	115.5%	-4.2	-27.7	99.8%
37	4	Refinitiv	232	123.0%	-3.4	-24.8	104.9%
42	1	Refinitiv	173	84.1%	-10.2	-75.9	60.8%
43	5	Refinitiv	205	105.5%	-6.4	-47.1	85.1%
44	5	Refinitiv	214	111.4%	-4.7	-34.9	96.2%
45	5	Refinitiv	228	120.3%	-3.6	-26.8	103.6%
46	5	Refinitiv	240	128.2%	-2.8	-22.5	108.9%
47	5	Refinitiv	246	132.1%	-2.3	-17.9	112.0%
52	1	Refinitiv	160	75.7%	-11.5	-76.1	52.0%
53	1	Refinitiv	155	72.4%	-11.4	-82.1	52.6%
54	1	Refinitiv	139	62.0%	-11.9	-88.9	49.4%
55	1	Refinitiv	164	78.4%	-11.2	-82.4	54.2%
56	1	Refinitiv	173	84.6%	-10.8	-74.9	56.7%
57	1	Refinitiv	164	78.5%	-11.0	-74.9	55.3%
58	1	Refinitiv	143	65.1%	-11.3	-80.6	53.7%
59	1	Refinitiv	158	74.8%	-10.9	-77.6	55.7%
63	1	Moody's	151	70.2%	-9.5	-79.1	64.9%
64	4	Moody's	195	98.6%	-5.9	-43.2	88.8%
65	4	Moody's	217	113.1%	-3.9	-29.7	101.2%
66	4	Moody's	229	120.6%	-2.7	-20.0	109.1%
67	4	Moody's	236	125.5%	-1.9	-13.6	114.6%
68	4	Moody's	243	129.9%	-1.2	-8.3	119.1%
69	1	Moody's	163	77.6%	-8.4	-72.7	72.4%
70	5	Moody's	200	101.7%	-4.8	-37.3	95.7%
71	5	Moody's	218	113.9%	-3.0	-22.5	107.0%
72	5	Moody's	231	122.5%	-2.1	-15.9	113.2%
73	5	Moody's	240	128.0%	-1.5	-10.8	117.1%
74	5	Moody's	243	129.9%	-1.2	-8.3	119.1%
75	1	Moody's	162	77.1%	-9.1	-72.3	67.7%
76	1	Moody's	163	77.7%	-9.0	-73.7	68.6%
77	1	Moody's	158	74.5%	-8.8	-73.4	69.9%
78	1	Moody's	158	74.4%	-8.7	-76.6	70.6%
Average	**All**	**All**	**185**	**92.4%**	**-7.3**	**-57.5**	**79.3%**

Note: the list of ESG themes corresponding to each portfolio ID can be found in Appendix 4. This table reports average WACI and carbon sensitivity of weights for our 78 rank-weighted ESG and carbon mixing portfolios. T-stats are heteroskedasticity adjusted following White (1980). Carbon sensitivity is estimated from the following pooled regression run separately for each portfolio: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. *Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability.* w_t^i *is the weight of stock i at rebalancing date t,* CI_t^i *its carbon intensity. Using the same notation, average WACI is computed as* $\overline{WACI} = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{N}(w_t^i CI_t^i))}{T}$, *with t running from Dec 2013 to Dec 2019 and T =7. The average is computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 74 (all Moody's themes are also in portfolio 68).*

Appendix

Table S4. Scope 1+2 Greenness and Green Dilution of Individual Optimised ESG and Carbon Mixing Portfolios, Controlling for Different Numbers of ESG Themes across Providers (Robustness Test)

Portfolio ID	Portfolio Group	ESG Rating Provider	Average Scope 1+2 WACI	Green Dilution based on Average Scope 1+2 WACI	Carbon Sensitivity	t-stat of Carbon Sensitivity	Green Dilution based on Carbon Sensitivity
4	1	MSCI	30	9.1%	-22.1	-107.4	21.1%
5	4	MSCI	45	17.6%	-19.3	-84.1	33.2%
6	4	MSCI	59	24.8%	-17.1	-74.6	43.2%
7	4	MSCI	62	26.4%	-15.4	-63.1	50.4%
8	4	MSCI	81	36.9%	-14.3	-61.8	55.4%
9	4	MSCI	102	48.3%	-12.6	-53.7	62.9%
13	1	MSCI	57	24.1%	-17.9	-83.7	39.6%
14	5	MSCI	156	77.9%	-10.2	-35.1	73.4%
15	5	MSCI	185	93.4%	-8.5	-30.0	81.0%
16	5	MSCI	204	104.1%	-6.9	-23.7	87.9%
17	5	MSCI	215	109.6%	-6.2	-21.1	90.9%
18	5	MSCI	198	100.6%	-6.3	-22.6	90.4%
22	1	MSCI	31	9.5%	-21.4	-101.3	24.1%
23	1	MSCI	38	13.4%	-20.5	-100.1	28.1%
24	1	MSCI	31	10.0%	-20.3	-104.1	28.7%
25	1	MSCI	53	21.8%	-18.9	-89.9	34.9%
26	1	MSCI	59	25.1%	-18.6	-87.6	36.5%
27	1	MSCI	53	21.9%	-18.4	-88.0	37.4%
28	1	MSCI	68	30.1%	-17.5	-80.1	41.0%
32	1	Refinitiv	50	20.3%	-22.9	-90.2	17.4%
33	4	Refinitiv	107	51.1%	-16.5	-51.2	45.6%
34	4	Refinitiv	141	69.7%	-11.5	-32.7	67.7%
35	4	Refinitiv	157	78.0%	-9.1	-25.1	77.9%
36	4	Refinitiv	179	90.3%	-7.1	-19.3	87.0%
37	4	Refinitiv	203	103.2%	-6.0	-16.7	91.8%
42	1	Refinitiv	69	30.5%	-19.8	-74.4	31.0%
43	5	Refinitiv	153	76.3%	-11.9	-34.3	65.9%
44	5	Refinitiv	183	92.5%	-8.4	-23.6	81.2%
45	5	Refinitiv	201	102.0%	-6.3	-18.5	90.6%
46	5	Refinitiv	218	111.2%	-5.3	-16.1	95.0%
47	5	Refinitiv	229	117.6%	-4.1	-12.4	99.9%
52	1	Refinitiv	61	26.0%	-22.2	-83.2	20.5%
53	1	Refinitiv	52	21.3%	-22.4	-86.5	19.5%
54	1	Refinitiv	52	21.3%	-21.9	-86.3	21.7%
55	1	Refinitiv	59	24.7%	-22.4	-86.0	19.7%
56	1	Refinitiv	69	30.6%	-21.4	-80.4	24.2%
57	1	Refinitiv	60	25.4%	-21.7	-81.2	22.9%
58	1	Refinitiv	48	19.0%	-21.9	-86.8	22.0%
59	1	Refinitiv	56	23.6%	-21.7	-81.8	22.8%
63	1	Moody's	55	22.8%	-19.3	-85.6	33.4%
64	4	Moody's	166	83.2%	-9.6	-30.7	76.1%

Appendix

65	4	Moody's	206	104.8%	-6.8	-21.3	88.3%
66	4	Moody's	229	117.6%	-4.1	-12.7	100.1%
67	4	Moody's	247	127.4%	-2.3	-7.1	108.0%
68	4	Moody's	256	131.9%	-1.1	-3.4	113.4%
69	1	Moody's	54	22.4%	-18.8	-84.4	35.6%
70	5	Moody's	162	81.0%	-7.8	-24.8	83.9%
71	5	Moody's	207	105.7%	-3.9	-11.9	100.9%
72	5	Moody's	238	122.5%	-2.3	-7.2	107.9%
73	5	Moody's	251	129.2%	-1.6	-4.9	111.2%
74	5	Moody's	256	131.9%	-1.1	-3.4	113.4%
75	1	Moody's	71	31.5%	-17.8	-75.4	40.0%
76	1	Moody's	63	27.3%	-18.2	-79.3	38.1%
77	1	Moody's	60	25.7%	-18.2	-77.4	38.3%
78	1	Moody's	62	26.6%	-18.0	-87.5	39.0%
Average	**All**	**All**	**119**	**57.7%**	**-13.8**	**-55.8**	**57.6%**

Note: the list of ESG themes corresponding to each portfolio ID can be found in Appendix 4. This table reports average WACI and carbon sensitivity of weights for our 78 rank-weighted ESG and carbon mixing portfolios. T-stats are heteroskedasticity adjusted following White (1980). Carbon sensitivity is estimated from the following pooled regression run separately for each portfolio: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. *Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability.* w_t^i *is the weight of stock i at rebalancing date t,* CI_t^i *its carbon intensity. Using the same notation, average WACI is computed as* $\overline{WACI} = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{N}(w_t^i CI_t^i))}{T}$, *with t running from Dec 2013 to Dec 2019 and T =7. The average is computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 74 (all Moody's themes are also in portfolio 68).*

Table S5. Scope 1+2+3 Greenness and Green Dilution of Individual Rank-weighted ESG and Carbon Mixing Portfolios (Robustness Test)

Portfolio ID	Portfolio Group	ESG Ratings Provider	Average Scope 1+2+3 WACI	Green Dilution based on Average Scope 1+2+3 WACI	Carbon Sensitivity	t-stat of Carbon Sensitivity	Green Dilution based on Carbon Sensitivity
1	2	MSCI	530	57.1%	-8.3	-66.2	71.7%
2	2	MSCI	832	104.9%	-4.2	-31.4	97.5%
3	2	MSCI	738	90.1%	-6.5	-49.1	83.0%
4	1	MSCI	342	27.2%	-14.1	-109.5	35.6%
5	3	MSCI	452	44.8%	-11.0	-86.6	55.1%
6	3	MSCI	510	54.0%	-9.3	-74.8	65.5%
7	3	MSCI	530	57.1%	-8.3	-66.2	71.7%
8	3	MSCI	607	69.3%	-7.0	-63.1	79.8%
9	3	MSCI	671	79.4%	-6.0	-58.7	86.3%
10	3	MSCI	718	86.9%	-5.1	-52.1	91.6%
11	3	MSCI	755	92.8%	-4.4	-46.8	96.0%
12	3	MSCI	785	97.5%	-3.8	-40.2	99.7%
13	1	MSCI	611	70.0%	-9.2	-78.0	66.5%
14	3	MSCI	759	93.3%	-5.7	-44.7	88.1%
15	3	MSCI	832	104.9%	-4.0	-36.7	98.3%
16	3	MSCI	876	111.9%	-3.2	-27.3	103.7%
17	3	MSCI	895	115.0%	-2.7	-24.4	106.5%
18	3	MSCI	854	108.5%	-2.9	-29.1	105.0%
19	3	MSCI	833	105.1%	-3.1	-31.7	104.0%
20	3	MSCI	815	102.3%	-3.3	-34.3	102.9%

Appendix

21	3	MSCI	785	97.5%	-3.8	-40.2	99.7%
22	1	MSCI	422	40.0%	-12.3	-96.1	47.1%
23	1	MSCI	427	40.8%	-12.1	-96.8	48.4%
24	1	MSCI	390	34.8%	-12.1	-91.4	48.2%
25	1	MSCI	582	65.3%	-10.2	-80.4	60.1%
26	1	MSCI	611	69.9%	-9.8	-80.9	62.8%
27	1	MSCI	611	69.9%	-9.5	-78.0	64.4%
28	1	MSCI	612	70.1%	-9.3	-77.7	65.6%
29	2	Refinitiv	788	98.0%	-5.3	-34.0	90.3%
30	2	Refinitiv	767	94.7%	-4.9	-32.2	93.2%
31	2	Refinitiv	844	106.8%	-4.9	-36.9	92.9%
32	1	Refinitiv	524	56.1%	-12.5	-85.9	45.6%
33	3	Refinitiv	682	81.3%	-8.4	-57.5	71.4%
34	3	Refinitiv	755	92.8%	-6.2	-42.4	84.9%
35	3	Refinitiv	773	95.6%	-5.1	-34.2	91.6%
36	3	Refinitiv	816	102.5%	-4.1	-26.7	97.8%
37	3	Refinitiv	857	109.0%	-3.3	-23.9	102.6%
38	3	Refinitiv	882	112.9%	-2.8	-19.7	106.1%
39	3	Refinitiv	883	113.0%	-2.4	-17.4	108.3%
40	3	Refinitiv	891	114.4%	-2.1	-15.1	110.5%
41	3	Refinitiv	909	117.3%	-1.6	-11.8	113.2%
42	1	Refinitiv	636	73.8%	-10.4	-76.0	58.6%
43	3	Refinitiv	746	91.3%	-6.6	-47.3	82.5%
44	3	Refinitiv	782	97.1%	-4.8	-34.8	93.3%
45	3	Refinitiv	836	105.6%	-3.6	-26.4	100.8%
46	3	Refinitiv	881	112.7%	-2.8	-22.4	105.9%
47	3	Refinitiv	902	116.1%	-2.3	-17.4	109.2%
48	3	Refinitiv	895	115.0%	-2.1	-15.7	110.3%
49	3	Refinitiv	904	116.4%	-1.8	-13.1	112.0%
50	3	Refinitiv	913	117.9%	-1.6	-12.3	113.1%
51	3	Refinitiv	909	117.3%	-1.6	-11.8	113.2%
52	1	Refinitiv	589	66.4%	-11.9	-75.8	49.9%
53	1	Refinitiv	576	64.4%	-11.7	-81.5	51.0%
54	1	Refinitiv	512	54.2%	-12.2	-88.5	47.4%
55	1	Refinitiv	606	69.1%	-11.4	-81.3	52.8%
56	1	Refinitiv	641	74.7%	-11.2	-75.1	54.1%
57	1	Refinitiv	615	70.6%	-11.2	-74.1	53.7%
58	1	Refinitiv	535	57.9%	-11.6	-80.0	51.2%
59	1	Refinitiv	572	63.8%	-11.3	-79.3	53.5%
60	2	Moody's	579	64.9%	-8.9	-78.5	68.0%
61	2	Moody's	799	99.7%	-3.7	-26.7	100.3%
62	2	Moody's	764	94.2%	-5.7	-44.3	88.0%
63	1	Moody's	554	60.8%	-9.9	-81.5	62.0%

Appendix

64	3	Moody's	716	86.5%	-6.2	-45.4	85.0%
65	3	Moody's	808	101.2%	-4.2	-31.5	97.3%
66	3	Moody's	858	109.1%	-2.9	-21.3	105.3%
67	3	Moody's	880	112.6%	-2.0	-14.8	110.7%
68	3	Moody's	902	116.0%	-1.4	-9.5	114.9%
69	1	Moody's	600	68.1%	-8.7	-74.8	69.1%
70	3	Moody's	730	88.8%	-5.1	-39.1	91.9%
71	3	Moody's	812	101.7%	-3.2	-23.6	103.3%
72	3	Moody's	867	110.4%	-2.2	-16.9	109.5%
73	3	Moody's	895	115.0%	-1.6	-11.9	113.1%
74	3	Moody's	902	116.0%	-1.4	-9.5	114.9%
75	1	Moody's	603	68.7%	-9.4	-74.2	64.8%
76	1	Moody's	627	72.4%	-9.2	-74.6	66.4%
77	1	Moody's	612	70.1%	-8.9	-73.5	67.9%
78	1	Moody's	530	64.9%	-8.9	-78.5	68.0%
Average	**All**	**All**	**712**	**86.0%**	**-6.5**	**-50.4**	**82.9%**

Note: the list of ESG themes corresponding to each portfolio ID can be found in Appendix 4. The Scope 1+2+3 carbon intensity portfolios are both built and tested for green dilution using Scope 1+2+3 carbon emissions, rather than Scope 1+2 carbon emissions in other specifications. This table reports average WACI and carbon sensitivity of weights for our 78 rank-weighted ESG and carbon mixing portfolios. T-stats are heteroskedasticity adjusted following White (1980). Carbon sensitivity is estimated from the following pooled regression run separately for each portfolio: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. *Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability.* w_t^i *is the weight of stock i at rebalancing date t,* CI_t^i *its carbon intensity. Using the same notation, average WACI is computed as* $\overline{WACI} = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{N}(w_t^i CI_t^i))}{T}$, *with t running from Dec 2013 to Dec 2019 and T =7. The average is computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 21 (all MSCI themes are also in portfolio 12), 51 (all Refinitiv themes are also in portfolio 41), 74 (all Moody's themes are also in portfolio 68), and 78 (Moody's lone Environmental score is also in portfolio 60).*

Table S6. Scope 1+2+3 Greenness and Green Dilution of Individual Optimised ESG and Carbon Mixing Portfolios (Robustness Test)

Portfolio ID	Portfolio Group	ESG Ratings Provider	Average Scope 1+2+3 WACI	Green Dilution based on Average Scope 1+2+3 WACI	Carbon Sensitivity	t-stat of Carbon Sensitivity	Green Dilution based on Carbon Sensitivity
1	2	MSCI	226	23.1%	-15.8	-62.8	49.1%
2	2	MSCI	771	96.0%	-7.9	-25.3	82.4%
3	2	MSCI	554	67.0%	-11.6	-38.6	67.0%
4	1	MSCI	118	8.7%	-22.3	-105.8	21.8%
5	3	MSCI	173	16.1%	-19.5	-80.8	33.5%
6	3	MSCI	219	22.3%	-17.3	-72.4	42.9%
7	3	MSCI	226	23.1%	-15.8	-62.8	49.1%
8	3	MSCI	294	32.2%	-14.7	-61.8	54.0%
9	3	MSCI	373	42.8%	-13.0	-54.0	61.0%
10	3	MSCI	427	50.0%	-11.7	-47.5	66.7%
11	3	MSCI	496	59.3%	-10.1	-41.1	73.2%
12	3	MSCI	591	71.9%	-8.8	-34.5	78.9%
13	1	MSCI	220	22.4%	-18.3	-85.4	38.6%
14	3	MSCI	661	81.3%	-10.1	-33.3	73.2%
15	3	MSCI	740	91.8%	-8.3	-28.5	80.8%
16	3	MSCI	828	103.7%	-6.7	-22.4	87.4%
17	3	MSCI	851	106.7%	-6.1	-20.0	90.0%

Appendix

18	3	MSCI	761	94.7%	-6.5	-22.5	88.6%
19	3	MSCI	718	88.9%	-6.9	-25.4	86.6%
20	3	MSCI	662	81.4%	-7.4	-27.8	84.6%
21	3	MSCI	591	71.9%	-8.8	-34.5	78.9%
22	1	MSCI	115	8.3%	-22.0	-103.9	23.1%
23	1	MSCI	137	11.2%	-21.0	-99.2	27.5%
24	1	MSCI	111	7.8%	-21.2	-103.9	26.4%
25	1	MSCI	196	19.1%	-19.5	-91.9	33.8%
26	1	MSCI	230	23.7%	-19.2	-87.5	35.1%
27	1	MSCI	206	20.4%	-18.6	-90.0	37.2%
28	1	MSCI	252	26.6%	-18.2	-82.8	39.3%
29	2	Refinitiv	613	74.9%	-9.7	-24.5	75.1%
30	2	Refinitiv	579	70.4%	-9.3	-24.3	76.7%
31	2	Refinitiv	694	85.8%	-10.1	-27.5	73.4%
32	1	Refinitiv	195	19.0%	-23.6	-88.8	16.5%
33	3	Refinitiv	408	47.5%	-16.8	-49.9	44.8%
34	3	Refinitiv	525	63.2%	-11.8	-32.0	66.2%
35	3	Refinitiv	571	69.3%	-9.2	-24.3	77.0%
36	3	Refinitiv	656	80.6%	-7.0	-18.4	86.2%
37	3	Refinitiv	721	89.4%	-6.0	-16.2	90.5%
38	3	Refinitiv	814	101.8%	-4.8	-12.8	95.6%
39	3	Refinitiv	799	99.7%	-4.1	-11.0	98.5%
40	3	Refinitiv	815	101.9%	-3.4	-9.4	101.4%
41	3	Refinitiv	853	107.0%	-2.5	-6.7	105.5%
42	1	Refinitiv	259	27.5%	-20.6	-75.0	29.0%
43	3	Refinitiv	511	61.3%	-12.5	-35.7	63.0%
44	3	Refinitiv	630	77.2%	-8.7	-24.0	79.0%
45	3	Refinitiv	723	89.6%	-6.3	-18.0	89.2%
46	3	Refinitiv	758	94.2%	-5.4	-16.1	92.9%
47	3	Refinitiv	805	100.6%	-4.2	-12.1	98.2%
48	3	Refinitiv	807	100.9%	-3.4	-9.7	101.3%
49	3	Refinitiv	821	102.8%	-3.1	-8.6	102.8%
50	3	Refinitiv	850	106.5%	-2.5	-7.0	105.2%
51	3	Refinitiv	853	107.0%	-2.5	-6.7	105.5%
52	1	Refinitiv	245	25.6%	-22.8	-81.3	19.6%
53	1	Refinitiv	196	19.1%	-23.1	-86.1	18.4%
54	1	Refinitiv	204	20.1%	-22.7	-85.0	20.2%
55	1	Refinitiv	225	22.9%	-23.0	-85.6	18.8%
56	1	Refinitiv	240	25.0%	-22.3	-82.8	22.0%
57	1	Refinitiv	244	25.5%	-22.1	-79.7	22.8%
58	1	Refinitiv	184	17.5%	-22.7	-85.1	20.1%
59	1	Refinitiv	204	20.1%	-22.3	-83.1	21.7%
60	2	Moody's	232	24.0%	-18.4	-86.3	38.4%

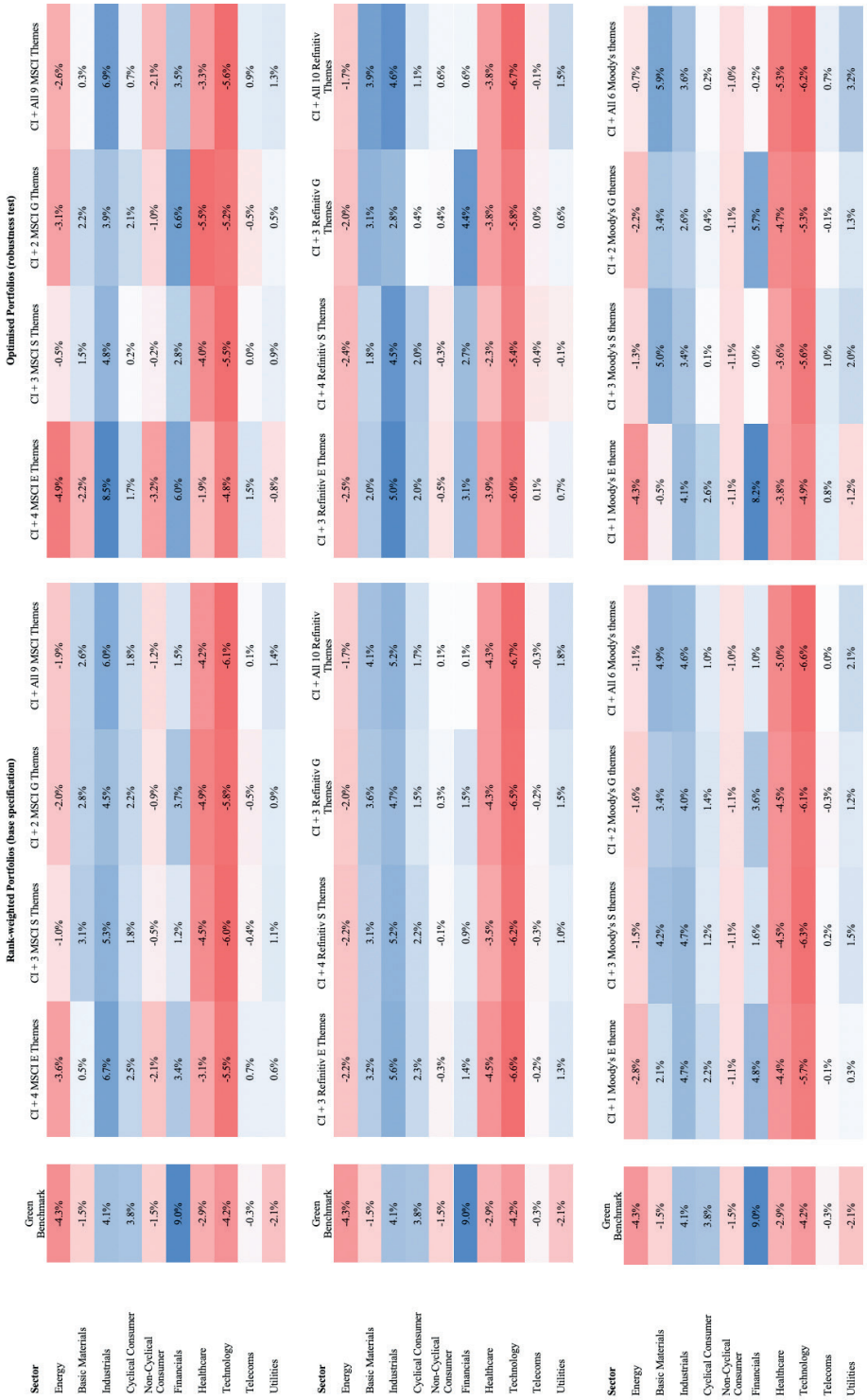
Appendix

61	2	Moody's	696	86.1%	-5.5	-16.4	92.7%
62	2	Moody's	586	71.3%	-10.9	-34.4	69.9%
63	1	Moody's	196	19.1%	-19.7	-87.0	32.6%
64	3	Moody's	551	66.7%	-10.4	-33.1	72.0%
65	3	Moody's	711	88.0%	-7.5	-23.0	84.4%
66	3	Moody's	801	100.0%	-4.6	-14.0	96.4%
67	3	Moody's	856	107.4%	-2.8	-8.4	104.2%
68	3	Moody's	892	112.2%	-1.4	-4.4	109.8%
69	1	Moody's	200	19.7%	-19.4	-85.0	34.2%
70	3	Moody's	525	63.2%	-8.5	-26.6	80.1%
71	3	Moody's	729	90.4%	-4.4	-12.9	97.5%
72	3	Moody's	854	107.2%	-2.7	-8.2	104.5%
73	3	Moody's	881	110.7%	-1.8	-5.6	108.1%
74	3	Moody's	892	112.2%	-1.4	-4.4	109.8%
75	1	Moody's	246	25.8%	-18.5	-76.7	37.8%
76	1	Moody's	231	23.8%	-18.8	-82.4	36.5%
77	1	Moody's	232	23.9%	-18.8	-79.1	36.5%
78	1	Moody's	226	24.0%	-18.4	-86.3	38.4%
Average	**All**	**All**	**496**	**59.3%**	**-12.4**	**-47.5**	**63.5%**

Note: the list of ESG themes corresponding to each portfolio ID can be found in Appendix 4. The Scope 1+2+3 carbon intensity portfolios are both built and tested for green dilution using Scope 1+2+3 carbon emissions, rather than Scope 1+2 carbon emissions in other specifications. This table reports average WACI and carbon sensitivity of weights for our 78 rank-weighted ESG and carbon mixing portfolios. T-stats are heteroskedasticity adjusted following White (1980). Carbon sensitivity is estimated from the following pooled regression run separately for each portfolio: $100{,}000 * w_t^i = \alpha + S \times \ln(CI_t^i) + \varepsilon_t^i$. *Pooling is carried out across stocks and time (each annual rebalancing date from Dec 2013 to Dec 2019) for each portfolio. Weights multiplied by 100,000 for better readability.* w_t^i *is the weight of stock i at rebalancing date t,* CI_t^i *its carbon intensity. Using the same notation, average WACI is computed as* $\overline{WACI} = \frac{\sum_{t=1}^{T}(\sum_{i=1}^{N}(w_t^i CI_t^i))}{T}$, *with t running from Dec 2013 to Dec 2019 and T =7. The average is computed excluding portfolios that are built using the same themes, i.e. portfolio IDs 21 (all MSCI themes are also in portfolio 12), 51 (all Refinitiv themes are also in portfolio 41), 74 (all Moody's themes are also in portfolio 68), and 78 (Moody's lone Environmental score is also in portfolio 60).*

Appendix

Table S7. Sector Deviations of Main ESG and Carbon Mixing portfolios Relative to the Scientific Beta Developed Cap-weighted Index



Note. CI = carbon intensity. This table shows the 2013-2020 average active weights (in percentage points) of portfolios relative to the Scientific Beta developed cap-weighted index. The list of themes included in each ESG pillar (E, S, or G) is available in Table 1.

Appendix

Table S8. Country Deviations of Main Rank-weighted ESG and Carbon Mixing Portfolios Relative to the Scientific Beta Developed Cap-weighted Index

Country	Green Benchmark	CI + 4 MSCI E Themes	CI + 3 MSCI S Themes	CI + 2 MSCI G Themes	CI + All 9 MSCI Themes
AT	0.3%	0.3%	0.4%	0.4%	0.4%
AU	1.2%	1.2%	2.1%	2.9%	2.0%
BE	0.4%	0.3%	0.4%	0.4%	0.4%
CA	0.8%	0.5%	1.4%	1.5%	1.1%
CH	-0.2%	-0.5%	-0.6%	-0.2%	-0.5%
DE	-0.1%	0.2%	-0.1%	0.3%	0.2%
DK	0.3%	0.4%	0.4%	0.5%	0.5%
ES	0.4%	0.8%	0.7%	0.5%	0.7%
FI	0.5%	0.7%	0.7%	0.9%	0.8%
FR	1.8%	2.3%	1.9%	1.6%	2.0%
GB	0.3%	0.9%	0.2%	1.7%	1.0%
GR	0.0%	0.0%	0.0%	0.0%	0.0%
HK	1.1%	1.2%	1.3%	1.3%	1.3%
IE	0.1%	0.1%	0.2%	0.3%	0.2%
IL	0.4%	0.3%	0.3%	0.5%	0.3%
IT	0.9%	0.8%	0.9%	0.8%	0.8%
JP	11.3%	11.5%	12.5%	6.5%	10.5%
KR	0.1%	-0.1%	0.0%	0.0%	-0.1%
NL	0.4%	0.5%	0.4%	0.7%	0.5%
NO	0.2%	0.3%	0.5%	0.5%	0.5%
NZ	0.4%	0.5%	0.5%	0.6%	0.5%
PT	0.1%	0.2%	0.2%	0.2%	0.2%
SE	1.7%	1.5%	1.5%	1.7%	1.5%
SG	1.1%	1.1%	1.3%	1.3%	1.3%
US	-23.8%	-25.1%	-27.3%	-24.8%	-26.1%

Country	Green Benchmark	CI + 3 Refinitiv E Themes	CI + 4 Refinitiv S Themes	CI + 3 Refinitiv G Themes	CI + All 10 Refinitiv Themes
AT	0.3%	0.4%	0.4%	0.4%	0.4%
AU	1.5%	2.1%	2.8%	3.6%	2.9%
BE	0.4%	0.4%	0.3%	0.3%	0.3%
CA	0.8%	0.4%	0.4%	0.9%	0.6%
CH	-0.2%	-0.3%	-0.2%	-0.5%	-0.4%
DE	-0.1%	1.4%	1.7%	0.9%	1.5%
DK	0.3%	0.5%	0.5%	0.5%	0.5%
ES	0.4%	1.2%	1.2%	0.6%	1.1%
FI	0.5%	1.0%	0.8%	0.6%	0.8%
FR	1.7%	3.3%	3.3%	1.6%	2.8%
GB	0.3%	0.7%	0.9%	1.1%	0.9%
GR	0.0%	0.0%	0.0%	0.0%	0.0%
HK	1.3%	1.3%	1.3%	1.3%	1.3%
IE	0.1%	0.2%	0.2%	0.3%	0.2%
IL	0.4%	0.3%	0.4%	0.3%	0.3%
IT	1.1%	1.1%	1.2%	0.8%	1.1%
JP	10.9%	11.2%	7.5%	10.0%	9.1%
KR	1.0%	1.0%	1.0%	0.9%	1.0%
NL	0.4%	0.6%	0.7%	0.5%	0.6%
NO	0.2%	0.4%	0.5%	0.4%	0.5%
NZ	0.5%	0.3%	0.3%	0.5%	0.4%
PT	0.1%	0.3%	0.3%	0.2%	0.3%
SE	1.6%	1.1%	1.2%	0.9%	1.0%
SG	1.0%	0.9%	1.0%	1.0%	1.0%
US	-24.7%	-29.8%	-28.0%	-27.3%	-28.3%

Country	Green Benchmark	CI + 1 Moody's E theme	CI + 3 Moody's S themes	CI + 2 Moody's G themes	CI + All 6 Moody's themes
AT	0.3%	0.4%	0.5%	0.4%	0.5%
AU	1.5%	1.7%	2.4%	2.7%	2.6%
BE	0.4%	0.6%	0.6%	0.5%	0.5%
CA	0.8%	0.7%	0.9%	1.3%	1.0%
CH	-0.2%	0.1%	-0.2%	-0.2%	-0.2%
DE	-0.1%	1.2%	1.9%	1.3%	1.7%
DK	0.3%	0.6%	0.6%	0.6%	0.7%
ES	0.4%	0.8%	1.1%	0.8%	1.1%
FI	0.5%	0.9%	0.9%	0.9%	1.0%
FR	1.7%	3.6%	4.5%	3.2%	4.4%
GB	0.3%	1.5%	1.5%	2.6%	2.2%
GR	0.0%	0.0%	0.0%	0.0%	0.0%
HK	1.3%	1.0%	0.8%	0.7%	0.7%
IE	0.1%	0.2%	0.2%	0.3%	0.3%
IL	0.4%	-0.1%	-0.1%	-0.1%	-0.1%
IT	1.1%	1.3%	1.6%	1.5%	1.5%
JP	10.9%	10.0%	8.3%	4.0%	6.3%
KR	1.0%	0.5%	0.4%	0.2%	0.3%
NL	0.4%	0.9%	0.9%	1.0%	1.0%
NO	0.2%	0.3%	0.5%	0.4%	0.5%
NZ	0.5%	0.3%	0.3%	0.3%	0.3%
PT	0.1%	0.2%	0.3%	0.2%	0.3%
SE	1.6%	1.8%	1.9%	1.6%	1.8%
SG	1.0%	0.9%	0.8%	0.8%	0.8%
US	-24.7%	-29.4%	-30.6%	-25.1%	-29.3%

Note. CI = carbon intensity. This table shows the 2013-2020 average active weights (in percentage points) of portfolios relative to the Scientific Beta developed cap-weighted index. The list of themes included in each ESG pillar (E, S, or G) is available in Table 1.

Appendix

Table S9. Country Deviations of Main Optimised ESG and Carbon Mixing Portfolios Relative to the Scientific Beta Developed Cap-weighted Index

Country	Green Benchmark	CI + 4 MSCI E Themes	CI + 3 MSCI S Themes	CI + 2 MSCI G Themes	CI + All 9 MSCI Themes
AT	0.3%	0.3%	0.4%	0.4%	0.4%
AU	1.5%	1.4%	2.4%	3.3%	2.3%
BE	0.4%	0.4%	0.4%	0.4%	0.4%
CA	0.8%	0.5%	1.4%	1.5%	1.1%
CH	-0.2%	-0.5%	-0.6%	-0.2%	-0.5%
DE	-0.1%	0.2%	-0.1%	0.3%	0.1%
DK	0.3%	0.4%	0.4%	0.5%	0.4%
ES	0.4%	0.8%	0.7%	0.5%	0.7%
FI	0.5%	0.6%	0.6%	0.9%	0.8%
FR	1.7%	2.2%	1.9%	1.6%	2.0%
GB	0.3%	0.9%	0.2%	1.8%	1.0%
GR	0.0%	0.0%	0.0%	0.0%	0.0%
HK	1.3%	1.3%	1.4%	1.4%	1.4%
IE	0.1%	0.1%	0.2%	0.3%	0.2%
IL	0.4%	0.3%	0.4%	0.5%	0.3%
IT	1.1%	0.9%	1.0%	0.9%	0.9%
JP	10.9%	11.3%	12.2%	6.0%	10.2%
KR	1.0%	0.5%	0.6%	0.6%	0.5%
NL	0.4%	0.5%	0.4%	0.7%	0.6%
NO	0.2%	0.3%	0.5%	0.5%	0.4%
NZ	0.5%	0.5%	0.5%	0.6%	0.5%
PT	0.1%	0.2%	0.2%	0.2%	0.2%
SE	1.6%	1.5%	1.5%	1.6%	1.5%
SG	1.0%	1.1%	1.3%	1.3%	1.2%
US	-24.7%	-25.7%	-27.9%	-25.7%	-26.8%

Country	Green Benchmark	CI + 3 Refinitiv E Themes	CI + 4 Refinitiv S Themes	CI + 3 Refinitiv G Themes	CI + All 10 Refinitiv Themes
AT	0.3%	0.4%	0.4%	0.3%	0.3%
AU	1.0%	0.9%	2.1%	4.4%	2.3%
BE	0.5%	0.4%	0.2%	0.4%	0.3%
CA	0.8%	0.0%	0.1%	1.3%	0.2%
CH	-0.1%	-0.1%	0.4%	-0.2%	-0.1%
DE	-0.1%	1.8%	2.7%	0.8%	2.3%
DK	0.4%	0.5%	0.6%	0.4%	0.5%
ES	0.3%	1.6%	1.8%	0.4%	1.5%
FI	0.6%	1.2%	0.9%	0.4%	0.9%
FR	1.9%	4.7%	4.6%	1.3%	3.9%
GB	0.4%	1.3%	1.8%	2.8%	1.6%
GR	0.0%	0.0%	0.1%	0.0%	0.0%
HK	0.8%	0.8%	0.8%	0.7%	1.0%
IE	0.0%	0.3%	0.2%	0.2%	0.2%
IL	0.5%	0.2%	0.5%	0.3%	0.3%
IT	1.1%	1.3%	1.5%	0.9%	1.1%
JP	9.8%	10.1%	3.0%	7.0%	7.0%
KR	1.0%	1.1%	1.2%	1.1%	1.2%
NL	0.3%	0.9%	1.1%	0.7%	0.9%
NO	0.1%	0.4%	0.6%	0.5%	0.6%
NZ	0.5%	0.2%	0.1%	0.5%	0.2%
PT	0.0%	0.3%	0.5%	0.0%	0.4%
SE	1.9%	1.4%	1.9%	1.2%	1.4%
SG	0.8%	0.5%	0.5%	0.9%	0.4%
US	-24.7%	-29.8%	-28.0%	-27.3%	-28.3%

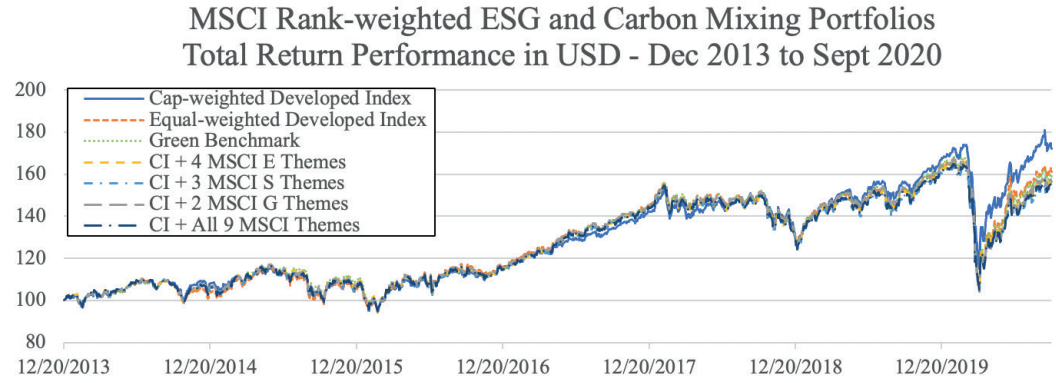
Country	Green Benchmark	CI + 1 Moody's E theme	CI + 3 Moody's S themes	CI + 2 Moody's G themes	CI + All 6 Moody's themes
AT	0.3%	0.4%	0.5%	0.4%	0.5%
AU	1.5%	1.7%	2.4%	2.7%	2.6%
BE	0.4%	0.6%	0.6%	0.5%	0.5%
CA	0.8%	0.7%	0.9%	1.3%	1.0%
CH	-0.2%	0.1%	-0.2%	-0.2%	-0.2%
DE	-0.1%	1.2%	1.9%	1.3%	1.7%
DK	0.3%	0.6%	0.6%	0.6%	0.7%
ES	0.4%	0.8%	1.1%	0.8%	1.1%
FI	0.5%	0.9%	0.9%	0.9%	1.0%
FR	1.7%	3.6%	4.5%	3.2%	4.4%
GB	0.3%	1.5%	1.5%	2.6%	2.2%
GR	0.0%	0.0%	0.0%	0.0%	0.0%
HK	1.3%	1.0%	0.8%	0.7%	0.7%
IE	0.1%	0.2%	0.2%	0.3%	0.3%
IL	0.4%	-0.1%	-0.1%	-0.1%	-0.1%
IT	1.1%	1.3%	1.6%	1.5%	1.5%
JP	10.9%	10.0%	8.3%	4.0%	6.3%
KR	1.0%	0.5%	0.4%	0.2%	0.3%
NL	0.4%	0.9%	0.9%	1.0%	1.0%
NO	0.2%	0.3%	0.5%	0.4%	0.5%
NZ	0.5%	0.3%	0.3%	0.3%	0.3%
PT	0.1%	0.2%	0.3%	0.2%	0.3%
SE	1.6%	1.8%	1.9%	1.6%	1.8%
SG	1.0%	0.9%	0.8%	0.8%	0.8%
US	-24.7%	-29.4%	-30.6%	-25.1%	-29.3%

Note. CI stands for carbon intensity. This table shows the 2013-2020 average active weights (in percentage points) of portfolios relative to the Scientific Beta developed cap-weighted index. The list of themes included in each ESG pillar (E, S, or G) is available in Table 1.

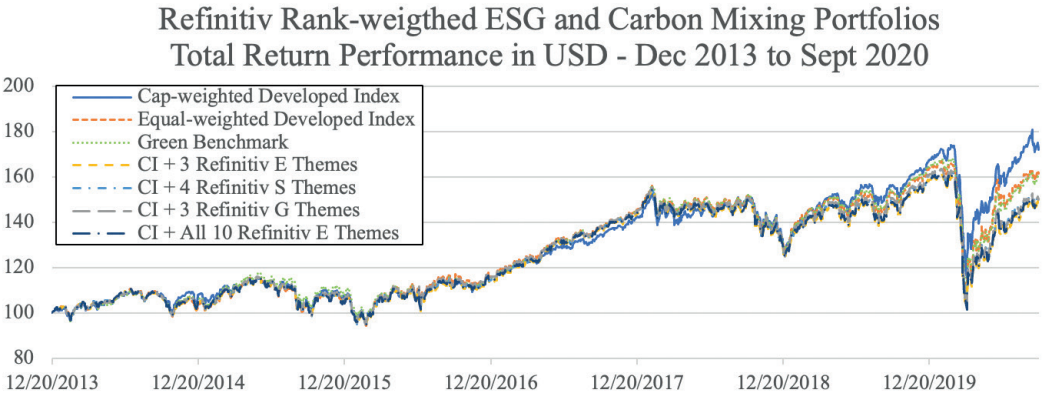
Appendix

Figure S10. Performance of Main Rank-weighted ESG and Carbon Mixing Portfolios

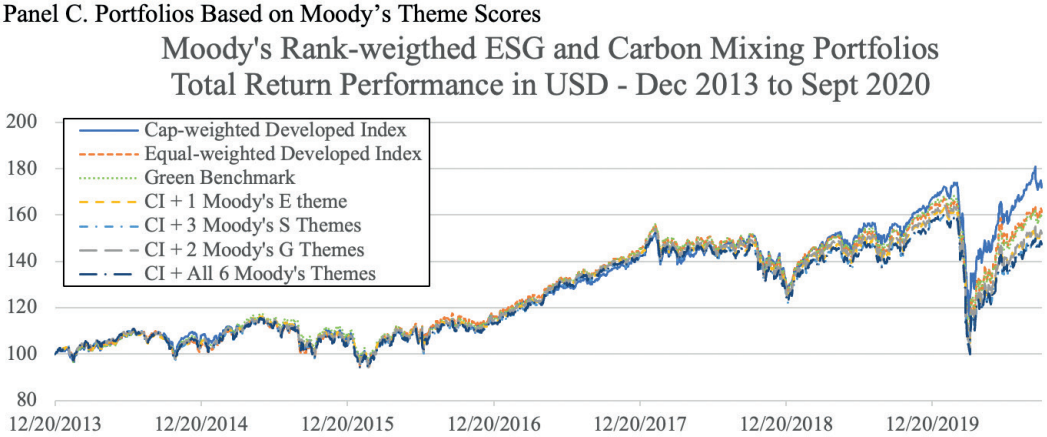
Panel A. Portfolios Based on MSCI Theme Scores



Panel B. Portfolios Based on Refinitiv Theme Scores



Panel C. Portfolios Based on Moody's Theme Scores

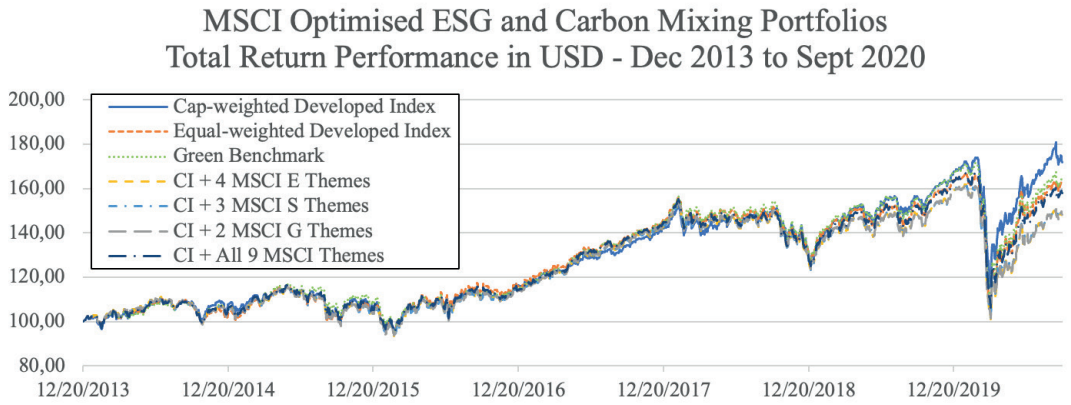


Note. CI stands for carbon intensity. Portfolio performance is measured using total USD returns and rebased to 100 in December 2013. The cap-weighted and equal-weighted developed indices are based on the Scientific Beta universe of global developed stocks.

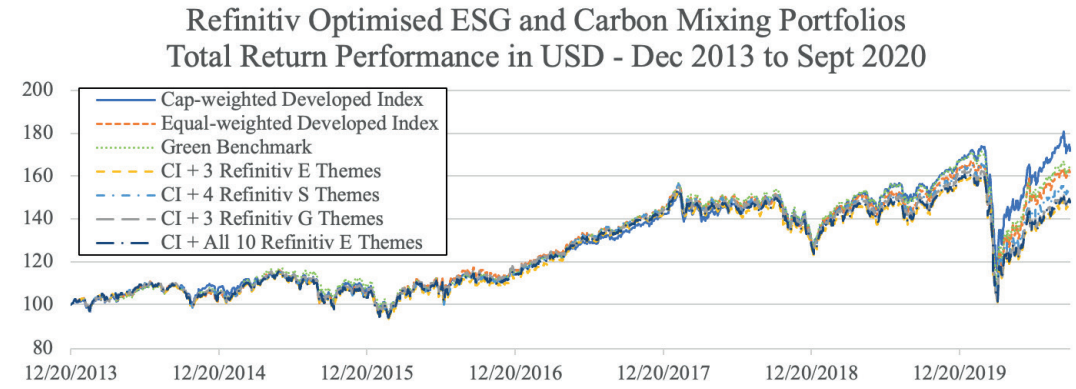
Appendix

Figure S11. Performance of Main Optimised ESG and Carbon Mixing Portfolios

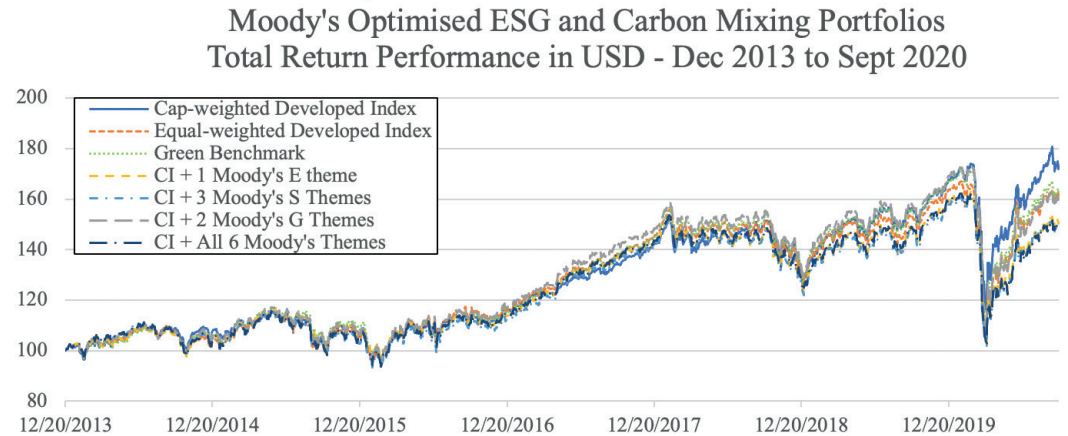
Panel A. Portfolios Based on MSCI Theme Scores



Panel B. Portfolios Based on Refinitiv Theme Scores



Panel C. Portfolios Based on Moody's Theme Scores



Note. CI stands for carbon intensity. Portfolio performance is measured using total USD returns and rebased to 100 in December 2013. The cap-weighted and equal-weighted developed indices are based on the Scientific Beta universe of global developed stocks.

References

References

- Amenc, N., Goltz, F., and Liu, V. (2022). "Doing Good or Feeling Good? Detecting Greenwashing in Climate Investing", *The Journal of Impact and ESG Investing*, 2:4, 57-68.
- Andresson, M., Bolton, P., and Samama, F. (2016). "Hedging Climate Risk", *Financial Analysts Journal,* 72:3, 13-32.
- Aouni, B., Doumpos, M., Pérez-Gladish, B., and Steuer, R. E. (2018). "On the increasing importance of multiple criteria decision aid methods for portfolio selection", *Journal of the Operational Research Society*, 69:10, 1525-1542.
- Ardia, D., Bluteau, K, Boudt, K., and Inghelbrecht, K. (2021) "Climate Change Concerns and the Performance of Green Versus Brown Stocks", Forthcoming, *Management Science*.
- Aswani, J., Raghunandan, A., and Rajgopal, S. (2023) "Are Carbon Emissions Associated with Stock Returns?". Forthcoming, *Review of Finance*.
- Atz, U., Van Holt, T., Liu, Z. Z., and Bruno, C. C. (2022). "Does sustainability generate better financial performance? review, meta-analysis, and propositions", *Journal of Sustainable Finance & Investment*, 13:1, 802-825
- Avramov, D., Cheng, S., Lioui, A., and Tarelli, A. (2021). "Sustainable Investing with ESG Rating Uncertainty", *Journal of Financial Economics*, 145:2, 642-664.
- Berg, F., Kölbel, J. F., and Rigobon R. (2022). "Aggregate Confusion: The Divergence of ESG Ratings", *Review of Finance*, 26:6, 1315–1344.
- Bolton, P. and Kacperczuk, M. (2021). "Do investors care about carbon risk?", *Journal of Financial Economics*, 142:2, 517-549.
- Bruno, G., Esakia, M., and Goltz, F. (2021). "Honey, I Shrunk the ESG Alpha: Risk-Adjusting ESG Portfolio Returns", *Journal of Investing*.
- Chan, Y., Hogan, K., Schwaiger, K., and Ang. A. (2020). "ESG in Factors", *The Journal of Impact and ESG Investing*, 1:1, 26-45.
- Coqueret, G. and Milhau, V. (2014). "Estimating covariance matrices for portfolio optimization", EDHEC Risk Institute Scientific Beta White Paper.
- Das, I. and Dennis, J. E. (1997). "A closer look at drawbacks of minimizing weighted sums of objectives for Pareto set generation in multicriteria optimization problems", *Structural and Multidisciplinary Optimization*, 14:1, 63–69.
- Ducoulombier, F. and Liu, V. (2021). "Carbon Intensity Bumps on the Way to Net Zero", *The Journal of Impact and ESG Investing* 1:3, 59-73.
- Gerard, B. (2022). "ESG and Socially Responsible Investment: A Critical Review", *Scandinavian Journal of Business Research*, 33:1, 61-83
- Hong, H. and Kacperczyk, M. (2009). "The price of sin: The effects of social norms on markets", *Journal of Financial Economics*, 93:1, 15-36.
- Liang, H. and Renneboog, L. (2021). "Corporate Social Responsibility and Sustainable Finance: A Review of the Literature", Oxford Research Encyclopedia (ORE) of Economics and Finance. Oxford University Press.
- Lindsey, L., Pruitt, S., and Schiller., P. (2021). "The Cost of ESG Investing", Working paper.

Madhavan, A., Sobczyk, A., and Ang, A. (2021). "Toward ESG Alpha: Analyzing ESG Exposures through a Factor Lens", *Financial Analysts Journal*, 77:1, 69-88.

References

- Matos, P. (2020). "ESG and Responsible Institutional Investing Around the World: A Critical Review", CFA Institute Research Foundation.
- Pedersen, L. H., Fitzgibbons, S., and Pomorski, L. (2021). "Responsible investing: The ESG-efficient frontier", *Journal of Financial Economics*, 142:2, 572-597.
- Pástor, L., Stambaugh, R. F., and Taylor, L. A. (2021). "Sustainable Investing in Equilibrium", *Journal of Financial Economics*, 142:2, 550-571.
- Pástor, L., Stambaugh, R. F., and Taylor, L. A. (2022). "Dissecting Green Returns", University of Chicago, Becker Friedman Institute for Economics Working Paper No. 2021-70.
- TCFD (2021). "Guidance on Metrics, Targets, and Transition Plans", October.
- White, H. (1980). "A heteroskedasticity-consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity", *Econometrica*, 48, 817-838.

About Scientific Beta

About Scientific Beta

Scientific Beta's aim is to encourage the entire investment industry to adopt the latest advances in smart factor and ESG/climate index design and implementation. Our institution was established in December 2012 by EDHEC-Risk Institute, one of the top academic institutions in the field of fundamental and applied research for the investment industry, as part of its mission to transfer academic know-how to the financial industry. Scientific Beta brings the same concern for scientific rigour and veracity to all the services that it provides to investors and asset managers. We offer the smart factor and ESG/Climate solutions that are most proven scientifically, with full transparency of both methods and associated risks.

On 31 January 2020, Singapore Exchange (SGX) acquired a majority stake in Scientific Beta. SGX continues to support our strong collaboration with EDHEC Business School, and the principles of independent, empirical-based academic research that have benefited our development to date.

Scientific Beta has developed two types of expertise over the years, responding to two of the major challenges that investors face:
- Smart Beta and, more particularly, factor investing.
- ESG, in particular climate investing.

To date, Scientific Beta has made offerings with two major types of climate objective available to investors:

Since 2015, we have offered products with financial objectives that respect ESG and carbon constraints. These correspond to the application of exclusion filters, the design of which allows the financial characteristics of the index to be conserved. This involves reconciling financial objectives and compliance with ESG norms and climate obligations. As such, our Core ESG, Extended ESG and Low Carbon filters can be integrated into smart beta or cap-weighted offerings in line with the financial objectives targeted by the investor.

Since 2021, Scientific Beta has also offered indices with pure climate objectives (Climate Impact Consistent Indices) that enable climate exclusions and weightings to be combined in order to translate companies' climate alignment engagement into portfolio decisions.

Since it was acquired by SGX in January 2020, Scientific Beta has accelerated its investments in the area of Climate Investing as part of the SGX Sustainable Exchange strategy, which is mobilising an investment of SGD20 million. In addition, EDHEC and Scientific Beta have set up a EUR1 million/year ESG Research Chair at EDHEC Business School.

With the aim of providing worldwide client servicing, Scientific Beta has a presence in Boston, London, Nice, Singapore and Tokyo. As of 31 July 2022, our indices had USD52.47bn in assets under replication. Scientific Beta has a dedicated team of 55 people who cover not only client support from Nice, Singapore and Boston, but also the development, production and promotion of our index offering. Scientific Beta signed the United Nations-supported Principles for Responsible Investment on 27 September 2016. We became an associate member of the Institutional Investor Group on Climate Change on 9 April 2021.

About Scientific Beta

Today, Scientific Beta devotes more than 40% of its R&D investment to climate investing and more than 45% of its assets under replication refer to indices with an ESG or climate focus. As a complement to its own research, Scientific Beta supports an important research initiative developed by EDHEC on ESG and climate investing and cooperates with Moody's ESG and ISS ESG for the construction of its ESG and climate indices.

On 27 November 2018, Scientific Beta was presented with the Risk Award for Indexing Firm of the Year 2019 by the prestigious professional publication Risk Magazine. On 31 October 2019, Scientific Beta received the Professional Pensions Investment Award for "Equity Factor Index Provider of the Year 2019." On 2 February 2022, Scientific Beta was named "Best Specialist ESG Index Provider" at the ESG Investing Awards 2022.

PRI Principles for Responsible Investment

IIGCC The Institutional Investors Group on Climate Change

Investor Group on Climate Change

INDUSTRY INNOVATION AWARDS FINALIST 2021 ESG | Scientific Beta

ESG Investing WINNER AWARDS 2022 Scientific Beta | Best Specialist ESG Index Provider

Scientific Beta Publications

Scientific Beta Publications

2023 Publications

- Amenc, N., F. Goltz and A. Naly. Green Dilution: How ESG Scores Conflict with Climate Investing. (June).
- Bruno, G., F. Goltz and B. Luyten. Firm-Level Exposure to Trade Policy Shocks: A Multi-dimensional Measurement Approach. (June).
- Aked, M. The Three Principles of Climate Impact Investing. (May).
- Aked, M. Navigating the Factor Menu - The Role of Macroeconomic Factors. (February).

2022 Publications

- Christiansen, E. Scientific Beta welcomes the NZAOA's Principles for Net-Zero-Aligned Benchmarks (December).
- Christiansen, E. Financing the Energy Transition: What is the Role of Fossil Fuels Divestment? (November).
- Mauguin, R. Scientific Beta Global Universe. (July).
- Christiansen, E., D. Aguet and N. Amenc. Climate Impact Consistent Indices. (March).
- Esakia, M and F. Goltz. Targeting Macroeconomic Exposures in Equity Portfolios: A Firm-Level Measurement Approach for Out-of-Sample Robustness. (February).

2021 Publications

- Amenc, N., G. Bruno and F. Goltz. Should ESG alpha Really be Positive? Assessing the Five Forces that Drive ESG Investment Returns. (December).
- Mahtani, R. Scientific Beta Enhanced ESG Reporting – Supporting Incorporation of ESG Norms and Climate Change Issues in Investment Management. (August).
- Bruno, G., M. Esakia and F. Goltz. "Honey, I Shrunk the ESG Alpha": Reactions of Investment Professionals (November).
- Amenc, N., F. Goltz, and V. Liu. Doing Good or Feeling Good? Detecting Greenwashing in Climate Investing (August).
- Aguet, D. Protecting your Equity Portfolio Against Inflation. (July).
- Christiansen, E., D. Aguet and N. Amenc. Scientific Beta Core ESG Filter: A Consensus and Norms-Based ESG Investing Approach. (August).
- Christiansen, E. Scoring against ESG? What are Market Participants' Views on ESG Scores? (May).
- Amenc, N., M. Esaki and F. Goltz. When Greenness is Mistaken for Alpha: Pitfalls in Constructing Low Carbon Equity Portfolios. (May).
- Bruno, G., M. Esakia and F. Goltz. "Honey, I Shrunk the ESG Alpha": Risk-Adjusting ESG Portfolio Returns. (April).
- Aguet, D., N. Amenc and F. Goltz. Reconciling Financial and Non-Financial Performance. (February).

2020 Publications

- Christiansen, E. and F. Ducoulombier. Scoring Against ESG? Avoiding the Pitfalls of ESG Scores in Portfolio Construction (December).
- Aguet, D. and E. Orecchini. Examining the Financial Performance and Risks of Smart Beta Strategies (December).

Scientific Beta Publications

• Ducoulombier, F. A Critical Appraisal of Recent EU Regulatory Developments Pertaining to Climate Indices and Sustainability Disclosures for Passive Investment. (December).

• Amenc, N., Christiansen, E. and F. Ducoulombier. ESG and Climate Change Integration Philosophy and Capabilities. (November).

• Amenc, N., Christiansen, E. and F. Ducoulombier. Scientific Beta ESG Index Customisation Capabilities. (November).

• Ducoulombier, F. and V. Liu. Carbon intensity bumps on the way to net zero. (October).

• Ducoulombier, F. Understanding the Importance of Scope 3 Emissions and the Implications of Data Limitations. (October).

• Ducoulombier, F. A Critical Appraisal of Recent EU Regulatory Developments Pertaining to Climate Indices and Sustainability Disclosures for Passive Investment. (October).

• Aguet, D., N. Amenc and K. Schneider. Why Should Investors Stick with their Factor Strategies? (September).

• Korovilas, D. Single-Factor indices. (August).

• Aguet, D. and E. Christiansen. Scientific Beta Core ESG Filter: A Consensus and Norms-Based ESG Investing Approach. (July).

• Aguet, D., N. Amenc and E. Shirbini. Scientific Beta Factor Analytics Services (SB FAS) - A New Tool to Analyse and Improve your Portfolio. (June).

• Amenc, N., E. Christiansen, F. Ducoulombier, F.Goltz, and V. Liu. ESG Engagement and Divestment: Mutually Exclusive or Mutually Reinforcing? (May)

• Amenc, N. and D. Korovilas. Robustness of Smart Beta Strategies: a Competitor Overview. (May).

• Aguet, D., N. Amenc and E. Shirbini. Q1 2020 Performance Analysis. (April).

• Amenc, N., G. Bruno and F. Goltz. Crowding Risk in Smart Beta Strategies. (April).

• Amenc, N., G. Bruno and F. Goltz. Ten Misconceptions about Smart Beta. (March).

• Amenc, N., G. Bruno and F. Goltz. Investability of Scientific Beta Indices. (March).

• Amenc, N., and F. Ducoulombier. Unsustainable Proposals (February).

• Amenc, N., F. Goltz, and B. Luyten. Intangible Capital and the Value Factor: Has Your Value Definition Just Expired? (February).

• Amenc, N., F. Goltz, B. Luyten and D. Korovilas. Assessing the Robustness of Smart Beta Strategies. (February).

• Aguet, D., N. Amenc. Improving Portfolio Diversification with Single Factor Indices. (January).

• Aguet, D., N. Amenc and F. Goltz. Managing Sector Risk in Factor Investing. (January).

• Aguet, D., N. Amenc and F. Goltz. What Really Explains the Poor Performance of Factor Strategies Over the Last Four years? (January).

Disclaimer

The information contained on the Scientific Beta website (the "information") has been prepared by Scientific Beta Pte solely for informational purposes, is not a recommendation to participate in any particular trading strategy and should not be considered as an investment advice or an offer to sell or buy securities. All information provided by Scientific Beta Pte is impersonal and not tailored to the needs of any person, entity or group of persons. The information shall not be used for any unlawful or unauthorised purposes. The information is provided on an "as is" basis. Although Scientific Beta Pte shall obtain information from sources which Scientific Beta Pte considers to be reliable, neither Scientific Beta Pte nor its information providers involved in, or related to, compiling, computing or creating the information (collectively, the "Scientific Beta Pte Parties") guarantees the accuracy and/or the completeness of any of this information. None of the Scientific Beta Pte Parties makes any representation or warranty, express or implied, as to the results to be obtained by any person or entity from any use of this information, and the user of this information assumes the entire risk of any use made of this information. None of the Scientific Beta Pte Parties makes any express or implied warranties, and the Scientific Beta Pte Parties hereby expressly disclaim all implied warranties (including, without limitation, any implied warranties of accuracy, completeness, timeliness, sequence, currentness, merchantability, quality or fitness for a particular purpose) with respect to any of this information. Without limiting any of the foregoing, in no event shall any of the Scientific Beta Pte Parties have any liability for any direct, indirect, special, punitive, consequential or any other damages (including lost profits), even if notified of the possibility of such damages.

All Scientific Beta Indices and data are the exclusive property of Scientific Beta Pte.

Information containing any historical information, data or analysis should not be taken as an indication or guarantee of any future performance, analysis, forecast or prediction. Past performance does not guarantee future results. In many cases, hypothetical, back-tested results were achieved by means of the retroactive application of a simulation model and, as such, the corresponding results have inherent limitations. The Index returns shown do not represent the results of actual trading of investable assets/securities. Scientific Beta Pte maintains the Index and calculates the Index levels and performance shown or discussed, but does not manage actual assets. Index returns do not reflect payment of any sales charges or fees an investor may pay to purchase the securities underlying the Index or investment funds that are intended to track the performance of the Index. The imposition of these fees and charges would cause actual and back-tested performance of the securities/fund to be lower than the Index performance shown. Back-tested performance may not reflect the impact that any material market or economic factors might have had on the advisor's management of actual client assets.

The information may be used to create works such as charts and reports. Limited extracts of information and/or data derived from the information may be distributed or redistributed provided this is done infrequently in a non-systematic manner. The information may be used within the framework of investment activities provided that it is not done in connection with the marketing or promotion of any financial instrument or investment product that makes any explicit reference to the trademarks licensed to Scientific Beta Pte (SCIENTIFIC BETA, SCIBETA and any other trademarks licensed to Scientific Beta Pte) and that is based on, or seeks to match, the performance of the whole, or any part, of a Scientific Beta index. Such use requires that the Subscriber first enters into a separate license agreement with Scientific Beta Pte. The Information may not be used to verify or correct other data or information from other sources.

The terms contained in this Disclaimer are in addition to the Terms of Service for users without a subscription applicable to the Scientific Beta website, which are incorporated herein by reference.

For more information, please contact:
Séverine Cibelly on: +33 493 187 863 or by e-mail to: severine.cibelly@scientificbeta.com

Scientific Beta HQ & Asia-Pacific
2 Shenton Way
#02-02
SGX Centre I
Singapore 068804
Tel: +65 6713 7578

Scientific Beta R&D
393 promenade des Anglais
BP 3116 - 06202 Nice Cedex 3
France
Tel: +33 493 187 863

Scientific Beta—Europe
10 Fleet Place, Ludgate
London EC4M 7RB
United Kingdom
Tel: +44 207 332 5600

Scientific Beta Germany
ONE, Brüsseler Straße 1-3
Frankfurt, 60327
Germany

Scientific Beta—North America
One Boston Place, 201 Washington Street
Office 2606, Boston, MA 02108
United States
Tel: +1 857 239 8891

Scientific Beta—Chicago
155 North Wacker Drive, Suite 4250
Chicago, IL 60606
United States
Tel: +1 312 803 4993

Scientific Beta—Melbourne
Level 27, 101 Collins Street
Melbourne Victoria 3000
Australia
Tel: +61 3 9653 6411

Scientific Beta—Sydney
Level 35, 100 Barangaroo Avenue
Sydney NSW 2000
Australia
Tel: +61 2 8114 4588

Scientific Beta
An SGX and EDHEC Venture