The economic function of sustainable investing and its application to portfolio selection

Hiroko Niikura / Tomonori Uchiyama, CMA / Kazuo Kakuma, CMA

Abstract

Sustainable investing addresses environmental and social issues by influencing firms' cost of capital through non-pecuniary investor preferences. Pecuniary returns and risks are also important to investors. In this study, we develop an optimal portfolio within a straightforward framework and demonstrate its application to equity and bond investments. Additionally, we discuss the expected returns of sustainable investing using a two-factor model that incorporates the market and ESG factors.

Hiroko Niikura
Dr. Niikura is a research engineer at Innovation Lab Dept., Nomura Asset Management (NAM). She earned her Ph.D. in Physics in 2019 from the University of Tokyo. In 2017, she was awarded the JSPS Research Fellowships for Young Scientists. She then joined NAM in 2019 and has been in her current position since April 2021.

Tomonori Uchiyama, CMA
Dr. Uchiyama is a Professor at the Graduate School of Management, Tokyo Metropolitan University. He has worked as a quantitative researcher at Nomura Securities and in asset management at Mitsui Trust Bank. He graduated from Kyoto University with a Ph.D. in Economics and was awarded the Securities Analysts Journal Prize in 2016.

Kazuo Kakuma, CMA
Mr. Kakuma is a career advisor at Innovation Lab of Nomura Asset Management (NAM). Prior to his current role in 2022, he held positions as the head of quantitative research at NAM. He graduated from the University of Tokyo with a master's degree in Geophysics and joined Nomura in 1988. He was awarded the awarded the Securities Analysts Journal Prize in 2012.

1 Introduction

Over the past decade, interest in linking asset management with environmental and social issues has surged. Government interventions through regulations and taxation are crucial for addressing externalities. However, international cooperation is challenging in cases like global warming, where negative externalities cross borders. Consequently, there is increasing demand for investors to take action. Given that economic activities rely on financing, encouraging investor action is plausible.

The benefits of mitigating climate change, for example, are not exclusive to sustainable investors but accrue to all investors. How does sustainable investing work in the competitive market? How should investors construct portfolios for sustainable investing? This study aims to explore these questions and provide guidelines for sustainable investing.

This paper consists of three parts. Section 2 presents a comprehensive look at the economic function of sustainable investing. Even if a firm's ESG characteristics impact its future cash flows, such as facing physical or transition risks associated with global warming, this outlook is already reflected in the current asset price or firm value and does not directly assist investors in decision-making.

However, if investors, on average, have non-pecuniary environmental, social, and governance (ESG) preferences, preferring to invest in high-ESG firms, the capital costs of these firms decrease, thereby promoting their sustainable management. Conversely, low-ESG firms face higher capital costs, discouraging unsustainable practices. Consequently, this preference for high-ESG firms also leads to a decrease in expected returns for sustainable investors' portfolios. The decrease in expected returns can be seen as a cost borne by sustainable investors to address negative externalities.

In Section 3, we derive the optimal portfolio of sustainable investments based on the discussion in Section 2. The optimal portfolio reflects both non-pecuniary ESG preferences and risk aversion concerning pecuniary returns. The optimal weight is determined relative to a given benchmark and does not require the input of expected returns, which are difficult to estimate accurately in practice. Even though estimating expected returns with significant errors is unnecessary, it is desirable to understand the nature of expected returns when constructing portfolios. Therefore, we also derive a CAPM incorporating ESG preferences and a two-factor model with the market and ESG factors. Despite the framework's simplicity, the models are consistent with existing studies. These allow for an easy understanding of the theoretical nature of the expected returns of sustainable investing portfolios.

In Section 4, we numerically apply the analytical solution for the optimal portfolio obtained in Section 3 to sustainable investing in stocks and bonds using environmental indicators. Finally, Section 5 presents the conclusions and future challenges.

2 The economic function of sustainable investing

How can sustainable investing contribute to society? How do firms' ESG characteristics and investors' ESG preferences affect asset prices and returns? There are often opposing views regarding the returns expected from sustainable investing. For instance, in a survey conducted by the Pension Fund Association in Japan among asset management companies, approximately 70% of the 103 respondents expect ESG investments to generate higher returns over the medium to long term.[1] In contrast, theoretical studies present a different view. The literature, including Heinkel, Kraus, and Zechner (2001), Hong, Wang, and Yang (2022), Pástor, Stambaugh, and Taylor (2021), Pedersen, Fitzgibbons, and Pomorski (2021), Baker et al. (2022a), Oehmke and Opp (2022), and Zerbib (2022), rigorously indicates that in equilibrium models, assets of high-ESG firms exhibit lower expected returns, or lower costs of capital, when investors have ESG preferences.

In this section, we conceptually summarize the economic function of sustainable investing using the following standard cash flow discount model:

$$p_{i,t} = \frac{E_t[d_{i,t+1}]}{(1+\mu_i)} + \frac{E_t[d_{i,t+2}]}{(1+\mu_i)^2} + \cdots, \tag{1}$$

where $p_{i,t}$ is the price of a security of firm i at time t, $\{d_{i,t+1}, d_{i,t+2}, \dots\}$ is the future cash flows, and μ_i is the discount rate or the cost of capital required by investors. The return on the security is defined by $r_{i,t+1} = (p_{i,t+1} + d_{i,t+1})/p_{i,t} - 1$.

We consider the cash flow in the numerator and the discount rate in the denominator as the channels through which ESG factors impact prices.

2.1 Cash flow channel

First, the ESG characteristics of a firm may relate to the cash flow $d_{i,t+j}$ in the numerator of (1). This relation can be either positive or negative. For example, firms offering environmentally friendly products may become more profitable if the demand for such products increases due to regulation changes or consumer preferences. In this case, the relation is positive. Conversely, firms facing physical or transition risks may incur higher costs in addressing these issues, leading to lower profitability. In this case, the relation is negative. Differences in $E_t[d_{i,t+j}]$ among firms that stem from ESG characteristics are reflected in the current price $p_{i,t}$, as shown in (1).

However, differences in $E_t[d_{i,t+j}]$ have no bearing on the expected returns. According to

[1] On page 23 of *Survey on stewardship activities of asset management companies* (in Japanese, March 6, 2023) by the Pension Fund Association.

the law of iterated expectations, from (1)

$$E_t[r_{i,t+1}] = \frac{E_t[p_{i,t+1} + d_{i,t+1}]}{p_{i,t}} - 1 = \mu_i. \tag{2}$$

Thus, the expected return on an asset equals the discount rate. The derivation of (2) is provided in Appendix A.

When there is information asymmetry, some better-skilled investors may be able to estimate the true $E_t[d_{i,t+j}]$ more accurately using ESG information, while less-skilled investors may not, due to differences in their abilities. In this case, the better-skilled investors may recognize that the market price of an asset differs from its intrinsic value and can earn additional high returns if the market price eventually converges to its intrinsic value. However, achieving positive excess returns over the market is a zero-sum game, as it results from the negative excess returns incurred by other investors. The average investor must hold the market portfolio and, therefore, cannot earn returns in excess of the market.

Accordingly, analyzing the impact of ESG characteristics on firms' finances to achieve higher returns can be regarded as one of active management's attempts to gain alphas by utilizing various types of information. Although active management plays a role in enhancing market efficiency by producing information, this paper focuses on the discount rate channel, which will be discussed further. Through the discount rate channel, sustainable investing performs a different economic function than active management.

2.2 Discount rate channel

Under standard asset pricing theory, the discount rate μ_i in the denominator of (1) is determined by investor preferences. Assets that investors hesitate to invest in due to high risk or other reasons have high discount rates. Conversely, assets preferred by investors have lower discount rates. While traditional asset pricing theory assumes that investors are only interested in pecuniary returns, Fama and French (2007) show that the above theory holds even when investors have non-pecuniary preferences (tastes) for certain types of assets.

Therefore, if investors, on average, prefer to invest in high-ESG firms, this preference is reflected in the discount rates. Consequently, assets of firms with high ESG scores are priced high from (1) and have low expected returns from (2). This low expected return, called the "greenium," represents a pecuniary cost that investors bear, compensating for non-pecuniary ESG preferences. On the other hand, the low cost of capital for high-ESG firms facilitates their expansion. Sustainable investing has the function of internalizing external diseconomies. This interpretation is consistent with arguments in existing studies discussed at the beginning of this section.

For example, carbon emissions are considered a cause of global warming. Given that managers' objective is to maximize firm value, firms are unlikely to be motivated to invest in mitigating global warming beyond the benefits to their own cash flow, even if there are benefits on a global scale. In other words, firms are unlikely to invest in projects that do not enhance their own value. However, when investors prefer to invest in green firms with low carbon emissions, the cost of capital decreases, making it easier for these firms to invest in projects.[2]

Conversely, for brown firms, the high cost of capital makes it difficult to continue or expand their operations, which is favorable for sustainable investors. Nevertheless, even brown firms can increase their value by transitioning to green, as this transition will attract sustainable investors and lower their cost of capital. This transition is also the perspective of the engagement investor. Suppose engagement can make a firm greener or less brown without negatively impacting its cash flow. In that case, the cost of capital will decrease, and the stock price will rise, driven by the preference of sustainable investors. This change will generate returns for engagement investors.[3] Thus, sustainable investing provides incentives for firms to address negative externalities by affecting the cost of capital.

For investors, ESG preferences lead to lower expected returns. Investors with higher ESG preferences than the average investor overweight green firms, resulting in lower portfolio expected returns.[4] The benefits associated with curbing global warming are enjoyed by society as a whole, not only by green investors but also by brown investors. Green investors are not pecuniarily rewarded for the lower expected returns, but they contribute to improving social welfare by lowering the cost of capital for green firms, thereby expanding the firms' green investments.

These are theoretical considerations. Empirical evidence also suggests low expected returns for high-ESG assets, as indicated by Bolton and Kacperczyk (2021, 2022), Baker et al. (2022a), and Hsu, Li, and Tsou (2023). Conversely, other studies, such as Nagy, Kassam, and Lee (2016) and Garvey et al. (2018), report high returns for high-ESG assets, indicating that an empirical consensus has yet to be reached. One reason may be the short history of sustainable investing, resulting in insufficient data to draw definitive statistical conclusions.

In particular, when investor ESG preferences unexpectedly increase, discount rates decline, resulting in high realized returns for high-ESG assets. Simultaneously, the low expected returns for these assets decline further, meaning that past realized returns are not a reliable guide for the future. Empirical evidence provided by Avramov et al. (2022), Pástor, Stambaugh,

[2]Green firms refer to companies with high ESG characteristics that generate positive externalities, whereas brown firms are ones with low ESG characteristics that produce negative externalities.

[3]Engagement can also enhance stock prices through the cash flow channel. If engagement improves a firm's cash flow beyond prior expectations, the stock price may rise. This effect is not unique to sustainable investing and is generally applicable.

[4]Since the aggregate of all investors' portfolios is the market portfolio, the market weight reflects the average investor's preferences. Therefore, holding a portfolio with the market weight implies that the investor has the same ESG preferences as the average, even if they are unaware of their ESG preferences. Investors who overweight high-ESG firms have higher ESG preferences than the average.

and Taylor (2022), and van der Beck (2022) supports this view.

3 Portfolio selection and expected returns

3.1 Optimal portfolio

The previous section conceptually discussed the economic function of sustainable investment. In this section, we derive the optimal portfolio for sustainable investing and analytically examine how sustainable investing affects discount rates, or expected returns, within a straightforward framework.

For incorporating ESG into optimal portfolios, Hong, Wang, and Yang (2022), Bolton, Kacperczyk, and Samama (2022), and Kaul et al. (2022) propose utility maximization approaches that impose exposure to ESG characteristics as an exogenous constraint. In contrast, we adopt a different approach by directly integrating non-pecuniary preferences for ESG characteristics into a utility function, following Pástor, Stambaugh, and Taylor (2021), Pedersen, Fitzgibbons, and Pomorski (2021), and Zerbib (2022).

Pástor, Stambaugh, and Taylor (2021) assume the existence of heterogeneous investors with different ESG preferences and an exponential utility. For simplicity, they assume that the market average of ESG characteristics is zero. Pedersen, Fitzgibbons, and Pomorski (2021) consider an economy with three types of investors: those who do not use ESG characteristics to estimate return distributions, those who use ESG characteristics but have no ESG preferences, and those who use ESG characteristics and also have ESG preferences. They assume a mean-variance utility. Zerbib (2022) assumes an exponential utility for investors without ESG preferences and for ESG investors who consider ESG integration and negative screening. These existing studies analyze market equilibrium in the context of investor heterogeneity.

Unlike previous studies, this research determines the optimal active weight according to the degree of ESG preference under a general utility function. This method uses a given benchmark and does not require the estimation of expected returns.

We assume a single-period model, as in the previous studies. There are n risky assets, whose returns $r = (r_1, \dots, r_n)'$ are normally distributed. Let μ be the expected return vector and Σ be the covariance matrix, i.e., $r \sim N(\mu, \Sigma)$. The risky assets possess ESG characteristics $s = (s_1, \dots, s_n)'$, which are deterministic. An asset i with a positive s_i yields a positive externality (e.g., a positive environmental impact); conversely, an asset with a negative s_i yields a negative externality (e.g., a negative environmental impact).

Let W_0 represent the initial wealth. The vector of investment amounts for each asset is $W_0 w$, where w is the portfolio's weight vector, and the ESG characteristic of the portfolio is denoted by $S \coloneqq W_0 w' s$. The future wealth $W \coloneqq W_0(1 + w'r)$ follows a normal distribution.

Assume that an investor cares not only about future wealth but also about the externalities that their portfolio generates, and maximizes their expected utility with respect to W and S. The utility function is given by $U(W,S) = E[u(W,S)]$, which satisfies the usual conditions. $U(W,S)$ represents the preferences of sustainable investors, such as "wanting to select a portfolio with high returns, low risk, and low carbon emissions." The investor's problem for sustainable investing is then as follows:

$$\max_{w} U(W,S). \tag{3}$$

Following standard practice, we exclude investments in the risk-free asset and impose the constraint that the sum of the weights equals 1. Appendix B shows that the solution to (3), or the optimal portfolio w^*, is given by

$$w^* = \frac{1}{\gamma}\Sigma^{-1}\left(\mu + \lambda s - \ell\iota\right), \tag{4}$$

where $\gamma > 0$ is the coefficient of relative risk aversion with respect to wealth W, $\lambda > 0$ is the marginal rate of substitution of the ESG characteristic S with respect to W, $\ell := \frac{\iota'\Sigma^{-1}(\mu+\lambda s)-\gamma}{\iota'\Sigma^{-1}\iota}$ is a scalar, and ι denotes a vector of ones. The marginal rate of substitution represents the trade-off between S and W, indicating the extent to which the investor is willing to enhance ESG characteristics in exchange for pecuniary returns. We henceforth refer to λ as the ESG preference.

The optimal portfolio w^* in (4) reflects the trade-off among expected return, risk (variance), and ESG characteristics. When $\lambda = 0$, w^* coincides with the traditional mean-variance optimal portfolio, which does not take ESG characteristics into account.

To actually calculate the optimal portfolio using (4), an estimate of the expected returns is necessary. Estimating expected returns is more difficult than estimating (co)variances, and a resulting optimal weight is highly sensitive to even slight differences in input values of expected returns. Hence, this study proposes a method that utilizes both the expected returns and the risk aversion implied by a given benchmark weight $w_b \in \mathbb{R}^n$. In this method, the relative weight of each asset to the benchmark is determined according to the ESG preference λ.

We assume that a given benchmark w_b is the optimal portfolio with a risk aversion of γ_b and an ESG preference of λ_b. Moreover, the investor's risk aversion is set to the same γ_b as the benchmark. Then, Appendix C shows that the investor's optimal portfolio (4) becomes

$$w^* = w_b + \Delta\lambda\,\Sigma^{-1}\left(s - \xi\iota\right), \tag{5}$$

where $\Delta\lambda := (\lambda - \lambda_b)/\gamma_b$ determines the degree of tilt, and $\xi := \frac{\iota'\Sigma^{-1}s}{\iota'\Sigma^{-1}\iota}$ is a scalar. The second term on the right-hand side is the active weight vector, the sum of its elements being zero. Given the ESG characteristics s, the benchmark w_b, and the covariance matrix Σ, implementing (5) is straightforward by defining $\Delta\lambda$ exogenously.

When the investor's ESG preference is at the benchmark level ($\lambda = \lambda_b$), $\Delta\lambda$ becomes 0, so the optimal portfolio coincides with the benchmark. As $\Delta\lambda$ increases, the optimal portfolio increasingly overweights assets with higher ESG characteristics s. The vector s is related to w^* via Σ^{-1}. The optimal weights also consider risk and are affected by return volatilities and correlations, in addition to the value of s.

The nature of (5) dictates that adding a constant uniformly to each element of s does not affect w^*. Multiplying each element of s by a constant uniformly scales the active weights by this ratio.

The optimal weight w^* in (5) is not necessarily nonnegative; some assets may have negative weights. When short selling is prohibited, one can impose a nonnegativity constraint on the optimization (see Appendix C.1).

3.2 Impact on expected returns

Formula (5) represents the active weight relative to a given benchmark based on $\Delta\lambda$, which indicates the strength of ESG preferences. However, as discussed in Section 2, the expected return on the portfolio w^* should also depend on $\Delta\lambda$. Although quantitatively capturing this influence is challenging, a qualitative interpretation can be obtained through the following model.

We then derive the expected return considering ESG preferences. Unlike Pástor, Stambaugh, and Taylor (2021), Pedersen, Fitzgibbons, and Pomorski (2021), and Zerbib (2022), we do not explicitly address the presence of heterogeneous investors. Instead, we consider the utility of the average investor. Specifically, let the risk aversion of the average investor be denoted by γ_m and the ESG preference by λ_m. The average investor is assumed to maximize the utility given by (3). Investment in the risk-free asset is allowed, with the risk-free rate denoted as r_f.

Although this setting is simple, we can obtain a CAPM similar to Proposition 1 of Pástor, Stambaugh, and Taylor (2021), Proposition 7 of Pedersen, Fitzgibbons, and Pomorski (2021), and Proposition 1 of Zerbib (2022), as well as a two-factor model similar to Proposition 4 of Pástor, Stambaugh, and Taylor (2021).

The market premium

Since the average investor's optimal portfolio is equal to the market portfolio $w_m \in \mathbb{R}^n$ in equilibrium, Appendix D shows that the following holds for the expected return on the market portfolio, $\mu_m := E[w_m' r]$:

$$\mu_m - r_f = \gamma_m \sigma_m^2 - \lambda_m s_m, \tag{6}$$

where $\sigma_m^2 := \mathrm{Var}(w_m' r)$ and $s_m := w_m' s$ represent the variance and the ESG characteristic of the market portfolio, respectively.

The first term on the right-hand side of equation (6) represents the risk premium. If investors, on average, do not have ESG preferences ($\lambda_m = 0$), the expected excess return on the market portfolio is determined solely by the risk premium. When $\lambda_m > 0$ and the market average ESG characteristic s_m is negative, the average investor tries to avoid investing in risky assets due to their negative externalities. Consequently, the expected excess return increases in equilibrium.

CAPM

From (6), the following ESG-adjusted CAPM for the expected return μ_i of asset i can be derived (see Appendix E):

$$\mu_i - r_f = \beta_i(\mu_m - r_f) - \lambda_m(s_i - \beta_i s_m), \tag{7}$$

where β_i represents the market beta of asset i, and $s_i - \beta_i s_m$ indicates the difference between the ESG characteristic of asset i and the market beta-adjusted average ESG characteristic $\beta_i s_m$.

When $\lambda_m = 0$, investors, on average, have no preference for ESG, and (7) corresponds to the traditional CAPM. When $\lambda_m > 0$, the expected return on asset i with a ESG characteristic s_i is lower. The impact on the expected return becomes more significant as the average investor's preference λ_m for ESG characteristics increases. This result indicates that the average investor's preference for non-pecuniary ESG characteristics affects the expected return, or the cost of capital, in equilibrium through their portfolio selection, consistent with the discussion in Section 2.

Two-factor model

Furthermore, a two-factor model comprising the market and ESG factors holds. We define an ESG factor portfolio tilted by ESG characteristics as $w_s := c\Sigma^{-1}(s - \beta s_m) \in \mathbb{R}^n$, where β represents the vector of the market betas, and the positive constant c is a scaling coefficient that determines the leverage size. w_s is a long-short portfolio depending on $s - \beta s_m$ and has a market beta of zero. The following two-factor model holds according to (7) (see Appendix F).

$$\mu_i - r_f = \beta_i(\mu_m - r_f) + \beta_i^s(\mu_s - r_f), \tag{8}$$

where $\mu_s := E[r_s]$, $\beta_i^s := \mathrm{Cov}(r_i, r_s)/\mathrm{Var}(r_s)$ represents the ESG beta of asset i, and $r_s := w_s' r$ is the return on the ESG factor portfolio.

When $\lambda_m > 0$, the ESG factor premium $\mu_s - r_f$ is negative, so assets with a high ESG beta β_i^s have lower expected returns. When $\lambda_m = 0$, $\mu_s - r_f = 0$. Furthermore, $\mu_s - r_f$ is proportional to the scaling coefficient c, and the β_i^s of each asset is inversely proportional to c. For example, if c is doubled, $\mu_s - r_f$ will double, but β_i^s will be halved, leaving $\beta_i^s(\mu_s - r_f)$ unaffected.

The representation given by (8) may be more useful than (7), as a high ESG beta implies that the asset has high ESG characteristics. Calculating the ESG factor based on the difference in returns between high-ESG and low-ESG stocks, similar to the size and value factors in the Fama-French factor model, makes it possible to estimate the ESG beta using (8), for example, through a time series regression. This approach allows for assessing the extent to which any asset or portfolio possesses ESG characteristics.[5]

Expected returns on portfolios

From the CAPM and the two-factor model, one can understand how sustainable investing affects the expected return of a portfolio. For any portfolio w_p, the difference in expected returns from a benchmark w_b can be derived using the CAPM (7):

$$(w_p - w_b)'\mu = (\beta_p - \beta_b)(\mu_m + \lambda_m s_m) - \lambda_m(s_p - s_b), \tag{9}$$

where β_p and β_b represent the market betas of the portfolio and benchmark, respectively. The terms $s_p := w_p' s$ and $s_b := w_b' s$ denote the ESG characteristics of the portfolio and benchmark. The first term on the right-hand side represents the premium arising from a difference in market betas, while the second term represents the premium arising from a difference in ESG characteristics.

This expression indicates that increasing the ESG characteristic s_p of the portfolio harms expected returns when $\lambda_m > 0$, which is consistent with the discussion in Section 2. The term $-(w_p - w_b)'\mu$ implies the additional cost borne in response to externalities compared to the benchmark.

Alternatively, based on the two-factor model (8), the difference between the expected returns of the portfolio and the benchmark can be expressed as follows:

$$(w_p - w_b)'\mu = (\beta_p - \beta_b)(\mu_m - r_f) + (\beta_p^s - \beta_b^s)(\mu_s - r_f), \tag{10}$$

where $\beta_p^s := w_p'\beta^s$ and $\beta_b^s := w_b'\beta^s$ are the ESG betas of the portfolio and the benchmark, respectively. Given $\lambda_m > 0$, when $\mu_s - r_f < 0$, an increase in the ESG beta of the portfolio results in a negative impact on the expected return compared to the benchmark.

[5](8) is a two-factor representation. However, empirically, it may be beneficial to include additional factors such as size and value for better accuracy.

4 Calculating optimal portfolio

This section calculates the optimal portfolio using ESG characteristics data to understand the essence of the optimal portfolio formula (5). Although (5) can be applied to individual securities, we will illustrate country allocation for ten developed economies. The investment assets considered are countries' stock indexes and 10-year government bonds. The ESG characteristics used are sovereign environmental indicators. Governments are considered to play the most crucial role in climate change mitigation (Nordhaus, 2021).

4.1 Data

The ten countries considered for investment are Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Sweden, the UK, and the US. For environmental indicators, we use two types: the Climate Change Performance Index (CCPI) from Germanwatch[6] and the Environmental Risk Management Score (E-score) from MSCI.

The CCPI tracks each country's efforts to address climate change and serves as an independent monitoring tool to enable comparisons of national progress. Specifically, it evaluates countries in four categories: greenhouse gas emissions (40%), renewable energy (20%), energy use (20%), and climate policy (20%). Since 2005, it has covered over 90% of greenhouse gas-emitting countries worldwide, publishing evaluations of 64 countries and regions (including the EU) annually as of 2022. The score ranges from 0 to 100.

The E-score is an indicator that assesses each country's management of environmental risk factors. It evaluates the management of natural resource risks and incorporates externalities and vulnerabilities to the environment. The score ranges from 0 to 10.

We use the 2022 edition of the CCPI and the E-score data as of June 2022. Since the two scores are on different scales, we standardize each of them by subtracting the mean and dividing by the standard deviation in the cross-section, resulting in z-values.

Figure 1 displays the z-values, with panel (a) illustrating the CCPI and panel (b) illustrating the E-score. Both are environmental indicators, but due to their differing definitions, they do not necessarily coincide. The correlation between them is 0.63. Both indicators show high values for Sweden and the UK and low values for the US and Belgium, while there is a significant difference for Canada. This suggests that even among environmental indicators, the choice of indicator can lead to different portfolio constructions. Berg, Kölbel, and Rigobon (2022) show that while credit ratings among rating agencies have a high correlation of 0.99, the correlations of ESG ratings among six agencies range from 0.38 to 0.71. Unlike financial information, the lack of a unified concept for these indicators complicates the practice of sustainable investing.

[6] https://germanwatch.org/en/CCPI

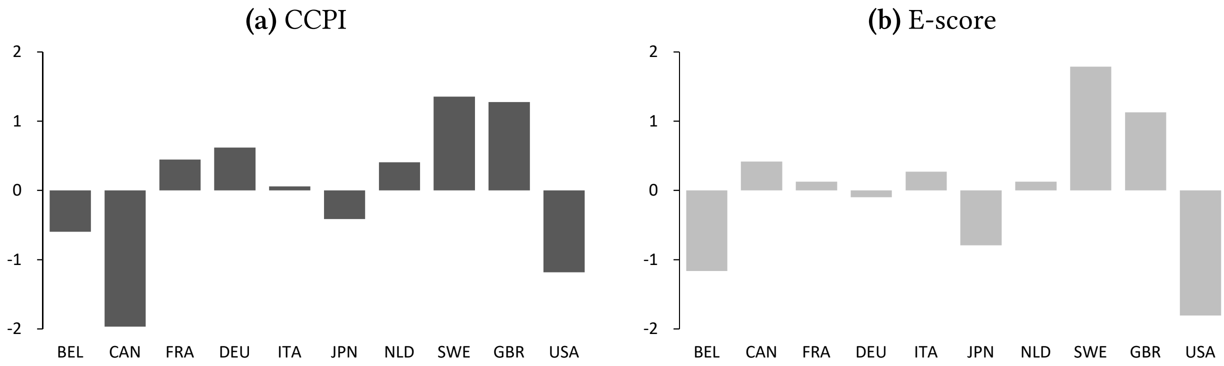

Figure 1: Environmental indicator (z-value)

Note: This figure represents the z-values of environmental indicators for 10 countries, standardized by subtracting the mean and dividing by the standard deviation in the cross-section. Panel (a) is based on the 2022 edition of the Germanwatch's Climate Change Performance Index (CCPI), and Panel (b) is based on the MSCI's Environmental Risk Management Score (E-score) as of June 2022.

Next, the ESG characteristic s is defined using the z-values. In (5), there is a relation between s and $\Delta\lambda$ such that if one is multiplied by a scalar and the other is divided by the same scalar, w^* remains unchanged. Therefore, it is convenient to set the value of the ESG characteristic to be of the same order as the expected return μ, and the value of the ESG preference to be of the same order as the risk aversion coefficient. Specifically, the z-values are transformed to calculate the ESG characteristic s_i for country i as follows:

$$s_i = z_i \times \tau\sigma_i^2, \tag{11}$$

where τ is a small positive constant, set to $\tau = 0.01$.[7] σ_i^2 represents the i-th diagonal element of Σ, which is the variance of return for country i.

Then, in (5), $\Delta\lambda$ is the exogenous variable of the model, and the degree of deviation from the benchmark of the optimal portfolio varies in proportion to this value. Here, we set $\Delta\lambda = 0.2$.[8] We estimate the covariance matrix Σ from monthly dollar-denominated data from December 1993 to May 2022, using the FTSE total equity index for each country, including dividends, and the returns of each country's 10-year government bonds obtained from Datastream.

4.2 Optimal portfolios

Figure 2 depicts the optimal active weight $w^* - w_b$ based on (5), with panel (a) representing equities and panel (b) representing bonds. The left graph employs CCPI for ESG character-

[7]This is because the variance of expected returns is much smaller than the variance of returns.

[8]To interpret this number, it is typically considered in financial literature that the risk aversion ranges from 1 to 10. For instance, with $\gamma_b = 5$ and $\lambda - \lambda_b = 1$, $\Delta\lambda = (\lambda - \lambda_b)/\gamma_b = 0.2$.

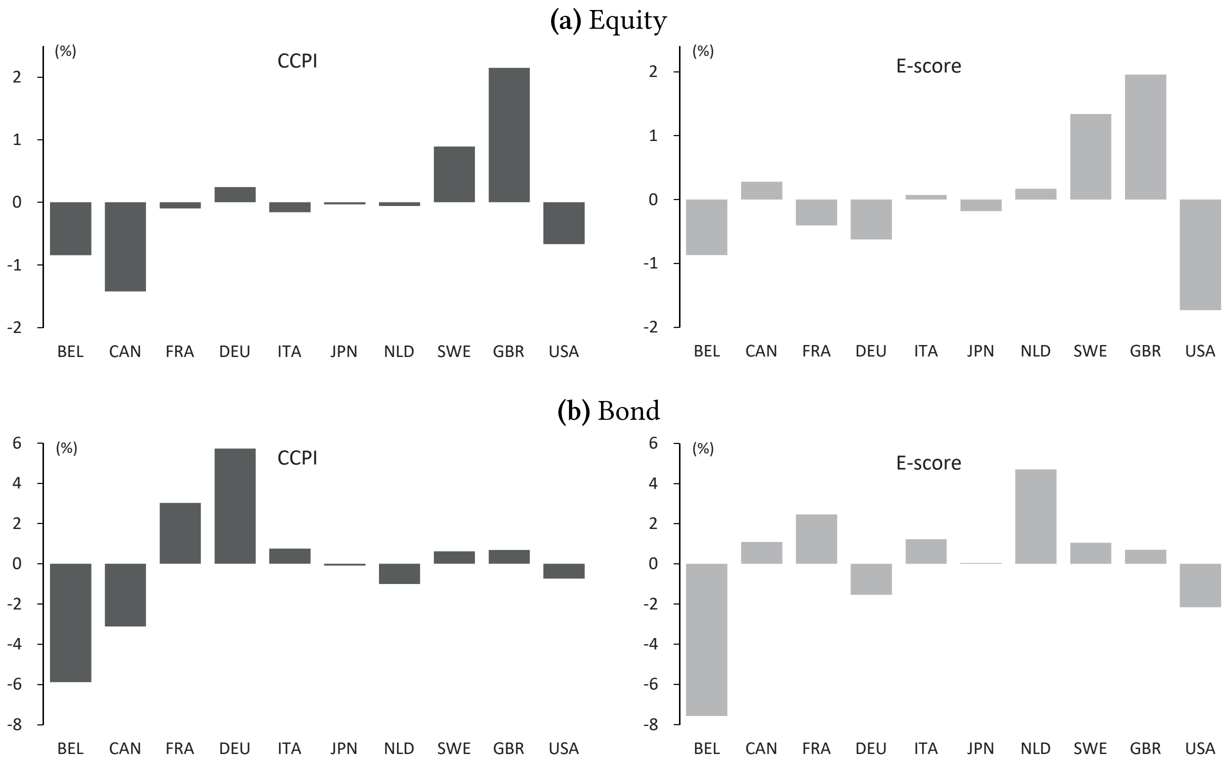

Figure 2: Optimal portfolio for sustainable investing

Note: This figure shows the optimal weights (difference from the benchmark) of the country allocations for the ten countries by (5), using the environmental indicators in Figure 1. We set the parameter $\Delta\lambda$ to 0.2. Panel (a) is for equities, and Panel (b) is for 10-year government bonds.

istics, while the right graph employs the E-score. The optimal portfolio considers not only ESG characteristics but also risk, reflecting the covariance of returns. Therefore, it does not necessarily align with the ranking of environmental indicator values shown in Figure 1.

The estimated annual tracking error for the equity portfolio relative to the benchmark is 33 bps for the CCPI and 35 bps for the E-score. For the bond portfolio, the tracking error is 28 bps with the CCPI and 27 bps with the E-score. Changing the value of $\Delta\lambda$, set to 0.2 here, alters the degree of tilt towards ESG characteristics and adjusts the tracking error. For instance, doubling the value of $\Delta\lambda$ also doubles both the active weight and the tracking error.[9]

4.3 Expected excess returns

As discussed, tilting towards assets with high ESG characteristics is likely to affect the portfolio's expected excess return. We now examine this effect for equity portfolios based on the

[9]From (5), the estimated tracking error is given by

$$\mathrm{Std}(r^* - r_b) = \Delta\lambda\sqrt{(s - \xi\iota)'\Sigma^{-1}(s - \xi\iota)},$$

where r^* and r_b denote the returns of the optimal portfolio and the benchmark, respectively.

two-factor model, (8) and (10). We present the results using the CCPI. The results are nearly identical when the E-score is used, as described in Appendix G.

The expected excess return of an asset is determined by the market factor premium $\mu_m - r_f$ and the ESG factor premium $\mu_s - r_f$, as well as the betas corresponding to each factor. Although estimating the factor premia is difficult, we assume a market premium $\mu_m - r_f$ of 6.8%, which is the historical average excess return of the equity market.[10]

Estimating the ESG premium $\mu_s - r_f$ is even more difficult. Just as the average investor's risk aversion determines the market premium, the ESG premium is determined by the average investor's ESG preference. If the average investor has no ESG preference, the ESG premium is zero, and as ESG preference increases, the negative ESG premium becomes larger. Considering that interest in sustainable investing, once less emphasized, has surged rapidly over the past five to ten years, the realized value of the ESG factor return has likely been positive while its expected value has decreased. Verily, it is challenging to estimate the ESG premium from historical data.

Therefore, we consider three cases for the ESG premium: (i) zero, (ii) half the level of the market premium in terms of the Sharpe ratio, and (iii) the same level as the market premium in terms of the Sharpe ratio. Case (ii) is intermediate between (i) and (iii). Since the ESG premium is negative, in Cases (ii) and (iii), it has the opposite sign of the market premium.

Using the market weights of the 10 countries at the end of May 2022 as the market portfolio w_m and the aforementioned estimate of the covariance matrix Σ, the market beta β_i of each asset is given in Column [1] of Panel (a) in Table 1. Multiplying the market beta by the market premium of 6.8% yields the value of the first term on the right-hand side of (8), $\beta_i(\mu_m - r_f)$. This value, shown in Column [3], corresponds to the expected excess return for each asset in Case (i).

Next, consider Cases (ii) and (iii). As mentioned in Section 3.2, the ESG beta and ESG premium depend on the scaling coefficient c (though their product does not depend on c). To facilitate comparison, we determine c so that the volatility of the ESG factor portfolio w_s matches that of the market portfolio w_m. This results in the ESG premium $\mu_s - r_f$ of -3.4% in Case (ii) and -6.8% in Case (iii). Column [2] shows the ESG beta for each country, calculated based on the ESG characteristics from the CCPI.

The market betas are around 1, while the ESG betas are around zero. By multiplying the ESG betas by the ESG premium, we obtain the second term on the right-hand side of (8), $\beta_i^s(\mu_s - r_f)$. Column [4] represents the values for Case (ii), and Column [6] for Case (iii). Adding the values in Column [3] to these gives the values in Columns [5] and [7], representing the expected excess return for each asset in their respective cases. The results show that

[10] This number is based on the average annual return on the FTSE World (including dividends, in USD) in excess of the risk-free rate from 1993 to 2022.

	Beta		Expected excess return				
	Market	ESG	Market	Case (ii)		Case (iii)	
	β	β^s	(c)	ESG (d)	Total (c+d)	ESG (e)	Total (c+e)
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
(a) Individual asset							
BEL	0.98	−0.02	6.66%	0.07%	6.73%	0.14%	6.80%
CAN	1.09	−0.29	7.42%	0.99%	8.42%	1.99%	9.41%
FRA	1.15	0.23	7.81%	−0.77%	7.04%	−1.55%	6.26%
DEU	1.30	0.32	8.84%	−1.10%	7.74%	−2.20%	6.63%
ITA	1.17	0.15	7.95%	−0.50%	7.45%	−1.00%	6.95%
JPN	0.68	0.01	4.65%	−0.04%	4.61%	−0.08%	4.57%
NLD	1.18	0.23	8.03%	−0.77%	7.26%	−1.54%	6.49%
SWE	1.32	0.59	8.96%	−2.01%	6.96%	−4.01%	4.95%
GBR	0.91	0.28	6.19%	−0.94%	5.24%	−1.89%	4.30%
USA	1.01	−0.04	6.86%	0.15%	7.00%	0.29%	7.15%
(b) Portfolio (active weight component)							
	0.00	0.02	0.00%	−0.05%	−0.05%	−0.11%	−0.11%

Table 1: Expected return on sustainable investing (equity portfolio based on CCPI)

Note: This table presents the results for equities using the CCPI from Figure 1 as environmental indicators. Panel (a) is based on (8). Panel (b) illustrates the optimal portfolio (deviation from a benchmark) according to (5), based on (10). $\Delta\lambda$ is set to 0.2, and the ESG premium is assumed to be −3.4% in Case (ii) and −6.8% in Case (iii).

the expected excess returns of assets with positive ESG betas decrease as the negative ESG premium increases. Conversely, assets with negative ESG betas exhibit the opposite.

Panel (b) of Table 1 corresponds to (10) and shows the active weight component $w^* - w_b$ of the optimal portfolio (5) by CCPI (left graph of Panel (a) in Figure 2), calculated based on the values in Panel (a) of Table 1. As shown in Column [1], the difference in the market beta from the benchmark is almost zero. Consequently, the value of the first term on the right-hand side of (10), the expected excess return relative to the benchmark, is also almost zero (Column [3]). Thus, the expected excess return relative to the benchmark comes from the second term on the right-hand side of (10). The difference in the ESG beta from the benchmark, as shown in Column [2], is 0.02. Therefore, the expected excess return over the benchmark is −5 bps in Case (ii) and −11 bps in Case (iii) for the tracking error of 33 bps.

4.4 Impact

Finally, we consider the impact on issuers' costs of capital. If the ESG premium is even closer to zero than in Case (ii) of Table 1, the loss due to the decrease in the expected return borne by sustainable investing becomes smaller. For example, if the ESG premium is −1%, the excess return over the benchmark in Panel (b) is only −2 bps. However, the expected excess returns of individual assets still vary according to their ESG characteristics. Even if the ESG premium is -1%, the expected excess return is 30 bps lower for green firms with an ESG beta of 0.3 and 30 bps higher for brown firms with an ESG beta of -0.3. Denoting the growth rate of the dividend d as g, the price according to the dividend discount model is $p = d/(\mu - g)$. When the dividend yield d/p is 2%, if the expected return decreases by 30 bps, the stock price will rise by 18%, and if the expected return increases by 30 bps, the stock price will decrease by 13%. As a result, green firms' stock prices increase by 31% compared to brown firms. Presumably, there has been such an effect on asset prices over the past ten years or so.

If many investors have ESG preferences, the negative ESG premium rises, widening the price differential and strengthening the impact on corporate financing. Consequently, this leads to a positive impact on the environment and society. In turn, the economy is also expected to benefit, which will be enjoyed not only by green investors but also by brown investors. For green investors, the decrease in utility due to the loss of expected returns is compensated by the increase in utility associated with ESG preferences. This is the economic function of sustainable investing.

5 Conclusion and discussion

In recent years, there have been growing expectations for the asset management industry to take action to address environmental and social issues. This study discusses portfolio selection for sustainable investing. The main conclusions are as follows.

First, the economic function of sustainable investing can be viewed as influencing firms' cost of capital through investors' non-pecuniary ESG preferences or tastes. This impact encourages firms to adopt sustainable management practices. On the other hand, ESG preferences reduce expected returns on investors' portfolios. This represents the cost incurred by sustainable investing in contributing to societal benefits.

Second, we derive the optimal portfolio for sustainable investing. This portfolio determines the optimal weights relative to a given benchmark without requiring the input of expected returns. We also derived both the CAPM and the two-factor model incorporating ESG, which is consistent with existing studies and within a straightforward framework. These models can help understand the nature of expected returns in sustainable investing.

Third, we numerically illustrate the applications of sustainable investing in stocks and bonds using environmental indicators through the analytical solution of the optimal portfolio.

For future research, there are aspects of optimal portfolios that this study has not considered. First, there is the component of risk aversion associated with vulnerabilities. For example, investors who are relatively vulnerable to warming risks, such as those living in coastal lowlands, should have a negative demand for assets similarly exposed to such risks.

Additionally, being relatively vulnerable to warming risks, these investors should have a positive demand for brown assets that are not exposed to warming risks. This is because holding such assets serves as a hedge against their exposure to warming risks (Baker, Hollifield, and Osambela, 2022b). Therefore, investors' relative vulnerability, along with their non-pecuniary ESG preferences, can also be key components of optimal portfolios.

Second, there is an issue of ambiguity: to what extent does sustainable investing effectively address environmental and social problems? The results of Berk and van Binsbergen (2022) and Zerbib (2022) differ on this matter. According to their respective methodologies and data, the former suggests a limited impact of sustainable investing on the cost of capital, while the latter indicates a significant influence. So, to what extent should ESG preferences be strengthened to contribute to solving these problems? It would be beneficial if we could quantitatively define goals in sustainable investment practices.

However, the issues that sustainable investing aims to address are highly uncertain and difficult to quantify. For instance, regarding global warming, the benefits of taking action on climate change and the losses of inaction will persistently accumulate over the long run. There also exists a two-way feedback loop wherein climate change affects economic growth, and economic growth affects climate change (Barnett, Brock, and Hansen, 2020; Giglio, Kelly, and Stroebel, 2021).

The challenges facing sustainable investing are complex. Ergo, we need to advance the science of sustainable investing further to make a more significant contribution to the environment and society.

Disclaimer: The opinions expressed in this study are solely those of the authors and do not necessarily reflect the views of their affiliated institutions.

References

Avramov, D., A. Lioui, Y. Liu, and A. Tarelli (2022) "Dynamic ESG equilibrium," SSRN Working Paper 3935174.

Baker, M., D. Bergstresser, G. Serafeim, and J. Wurgler (2022a) "The pricing and ownership of US green bonds," *Annual Review of Financial Economics*, 14(1), 415–437.

Baker, S. D., B. Hollifield, and E. Osambela (2022b) "Asset prices and portfolios with externalities," *Review of Finance*, 26(6), 1433–1468.

Barnett, M., W. Brock, and L. P. Hansen (2020) "Pricing uncertainty induced by climate change," *Review of Financial Studies*, 33(3), 1024–1066.

Berg, F., J. F. Kölbel, and R. Rigobon (2022) "Aggregate confusion: The divergence of ESG ratings," *Review of Finance*, 26(6), 1315–1344.

Berk, J. B. and J. H. van Binsbergen (2022) "The impact of impact investing," SSRN Working Paper 3909166.

Bolton, P. and M. Kacperczyk (2021) "Do investors care about carbon risk?," *Journal of Financial Economics*, 142(2), 517–549.

——— (2022) "Global pricing of carbon-transition risk," *Journal of Finance*, Forthcoming.

Bolton, P., M. Kacperczyk, and F. Samama (2022) "Net-zero carbon portfolio alignment," *Financial Analysts Journal*, 78(2), 19–33.

Fama, E. F. and K. R. French (2007) "Disagreement, tastes, and asset prices," *Journal of Financial Economics*, 83(3), 667–689.

Garvey, G. T., M. Iyer, and J. Nash (2018) "Carbon footprint and productivity: Does the "E" in ESG capture efficiency as well as environment?," *Journal of Investment Management*, 16(1), 59–69.

Giglio, S., B. Kelly, and J. Stroebel (2021) "Climate finance," *Annual Review of Financial Economics*, 13(1), 15–36.

Heinkel, R., A. Kraus, and J. Zechner (2001) "The effect of green investment on corporate behavior," *Journal of Financial and Quantitative Analysis*, 36(4), 431–449.

Hong, H. G., N. Wang, and J. Yang (2023) "Welfare consequences of sustainable finance," *Review of Financial Studies*, Forthcoming.

Hsu, P.-H., K. Li, and C.-Y. Tsou (2023) "The pollution premium," *Journal of Finance*, 78(3), 1343–1392.

Kaul, K., K. Schwaiger, M. Si, and A. Ang (2022) "Sustainable alpha in sovereign and corporate bonds," *Journal of Investment Management*, 20(2), 30–50.

Nagy, Z., A. Kassam, and L.-E. Lee (2016) "Can ESG add alpha? An analysis of ESG tilt and momentum strategies," *Journal of Investing*, 25(2), 113–124.

Nordhaus, W. D. (2021) *The spirit of green*, Princeton University Press.

Oehmke, M. and M. M. Opp (2022) "A theory of socially responsible investment," SSRN Working Paper 3467644.

Pástor, Ľ., R. F. Stambaugh, and L. A. Taylor (2021) "Sustainable investing in equilibrium," *Journal of Financial Economics*, 142(2), 550–571.

——— (2022) "Dissecting green returns," *Journal of Financial Economics*, 146(2), 403–424.

Pedersen, L. H., S. Fitzgibbons, and L. Pomorski (2021) "Responsible investing: The ESG-efficient frontier," *Journal of Financial Economics*, 142(2), 572–597.

van der Beck, P. (2022) "Flow-driven ESG returns," SSRN Working Paper 3929359.

Zerbib, O. D. (2022) "A sustainable capital asset pricing model (S-CAPM): Evidence from environmental integration and sin stock exclusion," *Review of Finance*, 26(6), 1345–1388.

Appendix

A Proof of Eq. (2)

From (1), the asset price $p_{i,t+1}$ of firm i at time $t+1$ is given by

$$p_{i,t+1} = \frac{E_{t+1}[d_{i,t+2}]}{(1+\mu_i)} + \frac{E_{t+1}[d_{i,t+3}]}{(1+\mu_i)^2} + \cdots. \tag{A1}$$

Since $E_t[E_{t+1}[d_{i,t+j}]] = E_t[d_{i,t+j}]$ for $j = 2, 3, \ldots$ from the law of iterated expectations, the expectation conditioned on time t becomes

$$E_t[p_{i,t+1}] = \frac{E_t[d_{i,t+2}]}{(1+\mu_i)} + \frac{E_t[d_{i,t+3}]}{(1+\mu_i)^2} + \cdots. \tag{A2}$$

Thus, (2) holds.

B Proof of Eq. (4)

B.1 General utility function

The utility function $U(W,S) = E[u(W,S)]$ is assumed to satisfy the usual conditions. That is, u is a differentiable, increasing, and concave function. The objective is

$$\max_{w} \; U(W,S) = E\left[u\left(W_0(1+w'r),\, W_0 w's\right)\right] \qquad \text{s.t.} \quad w'\iota = 1. \tag{A3}$$

The Lagrangian for this problem is given by

$$\mathcal{L}(w,\ell_1) = E\left[u\left(W_0(1+w'r),\, W_0 w's\right)\right] - \ell_1\left(w'\iota - 1\right), \tag{A4}$$

where ℓ_1 is the scalar Lagrange multiplier. The first-order condition with respect to w is

$$\begin{aligned} 0\iota &= E\left[u_W(W,S)W_0 r + u_S(W,S)W_0 s\right] - \ell_1\iota \\ &= E\left[u_W(W,S)\right]E\left[W_0 r\right] + \mathrm{Cov}\left(u_W(W,S),\, W_0 r\right) + W_0 E\left[u_S(W,S)\right]s - \ell_1\iota \\ &= W_0 E\left[u_W(W,S)\right]\mu + W_0^2 \Sigma E\left[u_{WW}(W,S)\right]w + W_0 E\left[u_S(W,S)\right]s - \ell_1\iota, \end{aligned} \tag{A5}$$

where the subscript of u denotes partial differentiation, and we use the multivariate Stein's lemma in the third line. Rearranging the above equation, the optimal portfolio w^* is as follows.

$$w^* = \frac{E\left[u_W(W,S)\right]}{-W_0 E\left[u_{WW}(W,S)\right]}\Sigma^{-1}\left(\mu + \frac{E\left[u_S(W,S)\right]}{E\left[u_W(W,S)\right]}s - \ell\iota\right), \tag{A6}$$

where $\ell := \frac{\ell_1}{W_0 E[u_W(W,S)]}$. In this equation, $\frac{E[u_W(W,S)]}{-W_0 E[u_{WW}(W,S)]}$ represents the inverse of the relative risk aversion, and $\frac{E[u_S(W,S)]}{E[u_W(W,S)]}$ represents the marginal rate of substitution.

Therefore, by letting the relative risk aversion be γ and the marginal rate of substitution be λ in (A6), the optimal portfolio is given by (4). The scalar ℓ is obtained by substituting (A6) into the constraint of problem (A3) and is given by $\ell = \frac{\iota'\Sigma^{-1}(\mu+\lambda s)-\gamma}{\iota'\Sigma^{-1}\iota}$.

B.2 Specific utility functions

As mentioned in Section 3.1, existing studies have assumed specific functional forms of exponential or mean-variance type for the utility function. In the following, we show the relation with the assumption of these specific utility functions.

We express the trade-off relation between W and S linearly as $W + \lambda S$, assuming an exponential utility function. That is, $u(W,S) = -e^{-a(W+\lambda S)}$, where $a > 0$ is the coefficient of absolute risk aversion. In this case, the relative risk aversion and the marginal rate of substitution are given by

$$-\frac{W_0 E[u_{WW}(W,S)]}{E\left[u_W(W,S)\right]} = aW_0, \qquad \frac{E\left[u_S(W,S)\right]}{E\left[u_W(W,S)\right]} = \lambda. \tag{A7}$$

The optimal portfolio using the relative risk aversion $\gamma = aW_0$ thus corresponds to (4) from (A6).

Alternatively, (4) is consistent with the mean-variance approach considering ESG characteristics. The objective of problem (A3) is as follows:

$$U(W,S) = E\left[-e^{-a(W+\lambda S)}\right] = -e^{-aW_0\left(1+E[w'r]-\frac{a}{2}W_0\mathrm{Var}(w'r)+\lambda w's\right)}. \tag{A8}$$

Maximizing this with respect to w is equivalent to maximizing the following with respect to w:

$$\underbrace{E[w'r]}_{\text{Expected return}} - \frac{\gamma}{2}\underbrace{\mathrm{Var}(w'r)}_{\text{Risk}} + \lambda \underbrace{w's}_{\substack{\text{ESG}\\ \text{characteristic}}}. \tag{A9}$$

The Lagrangian is given by

$$\mathcal{L}(w,\ell) = w'\mu - \frac{\gamma}{2}w'\Sigma w + \lambda w's - \ell\left(w'\iota - 1\right). \tag{A10}$$

Thus, the first-order condition implies (4).

C Proof of Eq. (5)

A benchmark w_b is assumed to be the optimal portfolio for the risk aversion γ_b and ESG preference λ_b according to (4).

$$w_b = \frac{1}{\gamma_b} \Sigma^{-1} \left(\mu + \lambda_b s - \ell_b \iota \right), \tag{A11}$$

where $\ell_b := \frac{\iota' \Sigma^{-1}(\mu + \lambda_b s) - \gamma_b}{\iota' \Sigma^{-1} \iota}$. The expected return μ_{imp} satisfying equation (A11) is given by:[*1]

$$\mu_{\text{imp}} = \gamma_b \Sigma w_b - \lambda_b s. \tag{A12}$$

μ_{imp} denotes the expected return implied by w_b.

For the investor's optimal portfolio (4), we set the risk aversion to be the same as the benchmark γ_b and use the implied return μ_{imp} for the expected return. We then obtain the following:

$$w^* = \frac{1}{\gamma_b} \Sigma^{-1} \left(\mu_{\text{imp}} + \lambda s - \frac{\iota' \Sigma^{-1}(\mu_{\text{imp}} + \lambda s) - \gamma_b}{\iota' \Sigma^{-1} \iota} \iota \right). \tag{A13}$$

By substituting (A12) into this, we have

$$w^* = w_b + \frac{\lambda - \lambda_b}{\gamma_b} \Sigma^{-1} s - \frac{\lambda - \lambda_b}{\gamma_b} \frac{\iota' \Sigma^{-1} s}{\iota' \Sigma^{-1} \iota} \Sigma^{-1} \iota. \tag{A14}$$

Therefore, by using $\Delta\lambda := (\lambda - \lambda_b)/\gamma_b$ and $\xi := \frac{\iota' \Sigma^{-1} s}{\iota' \Sigma^{-1} \iota}$, we have

$$w^* = w_b + \Delta\lambda \, \Sigma^{-1} \left(s - \xi \iota \right). \tag{A15}$$

C.1 Short sale constraint

The optimal portfolio w^* in (5) may contain negative elements. To ensure that all asset weights are nonnegative, one can impose a short sale constraint and solve the optimization problem numerically. Specifically, by setting the risk aversion to the same value as the benchmark γ_b in the objective function (A9) and substituting the implied returns μ_{imp} from (A12) for the expected returns, we have

$$w' \mu_{\text{imp}} - \frac{\gamma_b}{2} w' \Sigma w + \lambda w' s = \gamma_b \left[w' (\Sigma w_b + \Delta\lambda \, s) - \frac{1}{2} w' \Sigma w \right]. \tag{A16}$$

[*1] It can be easily verified by substituting μ_{imp} for μ in (A11).

Therefore, since γ_b is positive, the following quadratic programming problem can be solved numerically.

$$\begin{aligned} \max_{w} \quad & w'(\Sigma w_b + \Delta\lambda\, s) - \frac{1}{2} w'\Sigma w \\ \text{s.t.} \quad & w'\iota = 1, \\ & w_i \geq 0, \quad i = 1, \dots, n. \end{aligned} \tag{A17}$$

Naturally, if the nonnegativity constraint $w_i \geq 0$ for $i = 1, \dots, n$ is absent, or if it is present but not binding, the numerical solution to (A17) corresponds to the optimal portfolio w^* given by (5).

D Proof of Eq. (6)

The objective function of the average investor or the representative agent is given by

$$\max_{w} E\left[u\left(W_0(1 + w'(r - r_f\iota) + r_f), W_0 w's\right)\right]. \tag{A18}$$

This problem is the same as (A3), except that investment in risk-free assets is allowed. From the first-order condition of optimality, similar to Appendix B.1, and the fact that the optimal portfolio of the average investor is equal to the market portfolio w_m in equilibrium, we obtain

$$\mu - r_f\iota = \gamma_m \Sigma w_m - \lambda_m s. \tag{A19}$$

Multiplying both sides of (A19) by w_m', and using the expected return $\mu_m = w_m'\mu$, the variance $\sigma_p^2 = w_m'\Sigma w_m$, and the ESG characteristic $s_m = w_m's$ of the market portfolio, we have

$$\mu_m - r_f = \gamma_m \sigma_m^2 - \lambda_m s_m. \tag{A20}$$

E Proof of Eq. (7)

Rewriting (A20), we have

$$\gamma_m = \frac{\mu_m - r_f + \lambda_m s_m}{\sigma_m^2}. \tag{A21}$$

Substituting this into (A19), we obtain the CAPM that incorporates ESG considerations.

$$\begin{aligned} \mu - r_f\iota &= \frac{\Sigma w_m}{\sigma_m^2}(\mu_m - r_f + \lambda_m s_m) - \lambda_m s \\ &= \beta(\mu_m - r_f) + \lambda_m(\beta s_m - s). \end{aligned} \tag{A22}$$

$\Sigma w_m \in \mathbb{R}^n$ represents a vector $\mathrm{Cov}(r, r_m)$ consisting of the covariance between the returns of each asset and the market portfolio's return, thus $\beta := \frac{\Sigma w_m}{\sigma_m^2} \in \mathbb{R}^n$ denotes the market beta.

Since (A22) is in vector form, expressing it for asset i yields (7).

F Proof of Eq. (8)

From the definition of the market beta β, the ESG factor portfolio can be transformed as follows:

$$w_s = c\Sigma^{-1}(s - \beta s_m) = c\left(\Sigma^{-1}s - \frac{s_m}{\sigma_m^2}w_m\right). \tag{A23}$$

The market beta β_s of the ESG factor portfolio w_s is equal to zero.

$$\beta_s = w_s'\beta = c\left(\frac{s_m}{\sigma_m^2} - \frac{s_m}{\sigma_m^2}\right) = 0. \tag{A24}$$

Therefore, the expected excess return $\mu_s - r_f = w_s'(\mu - r_f\iota)$ of w_s is, from (A22),

$$\mu_s - r_f = w_s'(\mu - r_f\iota) = -\lambda_m s_s, \tag{A25}$$

where $s_s := w_s's$ represents the ESG characteristic of the ESG factor portfolio.

The variance $\sigma_s^2 := \mathrm{Var}(r_s)$ of the return r_s of the ESG factor portfolio is[*2]

$$\begin{aligned} \sigma_s^2 &= w_s'\Sigma w_s = c\left(s'\Sigma^{-1} - \frac{s_m}{\sigma_m^2}w_m'\right)\Sigma w_s \\ &= c\,(s_s - \beta_s s_m) = c s_s, \end{aligned} \tag{A26}$$

and the covariance vector between the returns on n risky assets and r_s is

$$\mathrm{Cov}(r, r_s) = \Sigma w_s = c(s - \beta s_m). \tag{A27}$$

Therefore, the vector of sensitivities or ESG betas of each asset to the ESG factor return, denoted as $\beta^s = \frac{\mathrm{Cov}(r,r_s)}{\mathrm{Var}(r_s)} \in \mathbb{R}^n$, is given by

$$\beta^s = \frac{\Sigma w_s}{\sigma_s^2} = \frac{s - \beta s_m}{s_s}. \tag{A28}$$

Substituting (A25) and (A28) into (A22), we obtain

$$\mu - r_f\iota = \beta(\mu_m - r_f) + \beta^s(\mu_s - r_f), \tag{A29}$$

which represents a two-factor model using the premiums $\mu_m - r_f$ and $\mu_s - r_f$ for the market factor and the ESG factor, respectively, along with the betas β and β^s for each factor. Since

[*2] Assuming Σ is a positive definite matrix, s_s is therefore positive.

(A29) is in vector form, expressing it for asset i yields (8).

Furthermore, since $s_s = w_s' s$, according to (A25), $\mu_s - r_f$ is proportional to the scaling factor c, and according to (A28), β^s is inversely proportional to c. Therefore, $\beta^s(\mu_s - r_f)$ is unaffected by c. Additionally, the ESG betas for the market portfolio w_m and the ESG factor portfolio w_s are 0 and 1, respectively.

G Expected return on sustainable investing (equity portfolio based on E-score)

	Beta		Expected excess return				
	Market	ESG	Market	Case (ii)		Case (iii)	
	β	β^s	(c)	ESG (d)	Total (c+d)	ESG (e)	Total (c+e)
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
(a) Individual asset							
BEL	0.98	−0.08	6.66%	0.28%	6.94%	0.55%	7.21%
CAN	1.09	0.25	7.42%	−0.84%	6.59%	−1.67%	5.75%
FRA	1.15	0.20	7.81%	−0.68%	7.13%	−1.37%	6.44%
DEU	1.30	0.17	8.84%	−0.58%	8.26%	−1.15%	7.68%
ITA	1.17	0.26	7.95%	−0.90%	7.06%	−1.79%	6.16%
JPN	0.68	−0.01	4.65%	0.02%	4.67%	0.04%	4.69%
NLD	1.18	0.21	8.03%	−0.71%	7.33%	−1.41%	6.62%
SWE	1.32	0.75	8.96%	−2.54%	6.43%	−5.07%	3.89%
GBR	0.91	0.28	6.19%	−0.96%	5.22%	−1.93%	4.26%
USA	1.01	−0.06	6.86%	0.22%	7.07%	0.43%	7.29%
(b) Portfolio (active weight component)							
	0.00	0.02	0.01%	−0.06%	−0.05%	−0.11%	−0.10%

Note: This table presents the results for equities using the E-score from Figure 1 as environmental indicators. Panel (a) is based on (8). Panel (b) illustrates the optimal portfolio (deviation from a benchmark) according to (5), based on (10). $\Delta\lambda$ is set to 0.2, and the ESG premium is assumed to be −3.4% in Case (ii) and −6.8% in Case (iii).