Sustainability Risk Premium: Evidence from Sustainability-linked Bonds

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Abstract

Sustainable investing has expanded rapidly, yet whether sustainability risk carries a market price remains unresolved. We develop a pricing framework in which sustainability-contingent claims are valued for their hedging role against reduced sustainability performance yielding a market price of sustainability risk, which increases in the share of sustainable capital participating in the market for such claims. Using sustainability-linked bonds (SLBs) as an empirical proxy, we estimate the market price of sustainability risk in the SLB market and find that these investors forgo about 0.55% of expected return to insure against downside sustainability outcomes, providing direct evidence of a sustainability risk premium. Our framework further explains why broad-based market tests yield mixed results: given the small proportion of sustainable investors, offsetting risk and non-pecuniary preference effects leave a negligible net premium in aggregate.

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1 Introduction

A central question in sustainable finance concerns whether investors' nonpecuniary preferences, the utility they derive from holding assets aligned with their sustainability goals, are reflected in asset prices. If such preferences exist to a sufficiently strong extent, they imply the existence of a sustainability risk premium, tied to fluctuations in sustainability outcomes, with broader consequences for firms' sustainability choices, capital allocations, and real economic outcomes. Understanding whether and how sustainability preferences are priced therefore has implications that extend well beyond portfolio construction.

Despite considerable attention from theoretical, empirical, experimental and survey-based research, this question remains unresolved[1]. Even the seemingly straightforward question of whether sustainability considerations affect financial returns has been debated since Hamilton et al. (1993) with subsequent studies reaching opposing conclusions across different markets and asset classes. Some find that assets with stronger ESG profiles underperform; others find the opposite.[2] Interpreting these findings is further complicated by the difficulty of separating taste-based preferences from standard financial motives, including the possibility that sustainability characteristics proxy for conventional risk exposures or cash flow differences (See, for example, Fama and French (2007)).

We argue that much of the mixed evidence reflects the characteristics of the testing environment rather than the absence of sustainability preferences. Traditional equity and bond markets are poorly suited for identifying such preferences for two primary reasons. First, sustainability-motivated investors represent only a small share of capital in broad asset markets (Berk and van Binsbergen, 2025), so any pricing effect driven by their preferences is mechanically diluted and difficult to detect. Second, sustainability preferences affect expected returns through offsetting channels: investors may accept lower expected returns for assets with better sustainability performance (Pástor et al., 2021; Pedersen et al., 2021), but they may also require compensation for exposure to sustainability risk (Avramov et al., 2022). Because these effects offset each other, the net pricing signal in traditional assets is small, even when underlying preferences are economically significant. Moreover, sustainability outcomes are often correlated with firms' cash flows and con-

[1] See Starks (2023) for a detailed discussion.

[2] See, for example, (Hong and Kacperczyk, 2009; Barber et al., 2021; Baker et al., 2022; Zerbib, 2019; Bolton and Kacperczyk, 2023; Edmans, 2011; Gompers et al., 2003).

ventional risk exposures, making sustainability-related pricing difficult to separate from standard financial motives.

These observations point to a more suitable testing environment: a sustainability-contingent claim such as a sustainability-linked bond (SLB) whose financial payoff increases when sustainability performance deteriorates. Such an instrument provides an explicit hedge against sustainability shortfalls, so investors with sustainability preferences value it for its insurance role. Thus, the claim's price reflects what investors are willing to pay for sustainability insurance rather than the nonpecuniary benefit of directly holding sustainable assets, making it a direct measure of the market price of sustainability risk. We develop a pricing framework based on this insight and use the SLBs as empirical proxies for such a claim. This setting provides a useful framework for reinterpreting the mixed evidence in the existing literature.

Our analysis makes three primary contributions. The first is theoretical. We develop a one-period equilibrium pricing model, building on Pástor et al. (2021), Pedersen et al. (2021), Avramov et al. (2022), among others, to show why a sustainability-contingent claim is a suitable instrument for identifying the sustainability risk premium (SRP). Because the claim pays off when sustainability outcomes deteriorate, it provides an explicit hedge against sustainability shortfalls, so its payoff moves directly with sustainability risk. Investors with sustainability preferences therefore value the claim for its insurance role. But unlike equity and bond instruments, this claim is a derivative: its price therefore reflects the amount investors are willing to pay for sustainability insurance, rather than the non-pecuniary benefit of directly holding sustainable assets. This makes the claim a direct measure of the market price of sustainability risk.

In our model the economy contains two representative risky assets and two investor types. The first risky asset is a standard market-index asset that delivers both financial payoffs and sustainability outcomes. The second is the sustainability-contingent claim, whose financial payoff increases when sustainability performance deteriorates. Investors are of two types: conventional investors, who care only about financial wealth, and sustainable investors, who derive utility from both financial wealth and sustainability performance. Both types optimally allocate their wealth across the two assets, and a risk-free asset.

In equilibrium, the expected excess return on the sustainability-contingent claim is dominated by its hedging role and can be written as $\beta\lambda$, where $\beta < 0$ captures the claim's exposure to sustainability shocks and λ is the market price of sustainability risk, which measures the expected return investors are willing to forgo to hedge one unit of sustainability risk. A higher λ reflects a stronger willingness to pay for insurance against adverse sustainability shocks; because the contingent claim appreciates when sustainability performance deteriorates, a larger λ raises its price and lowers its expected return.

A central implication of our model is that λ is identified in asset prices only when the market contains a sufficient number of sustainable investors. The parameter λ is jointly determined by the magnitude of risk in sustainability payoffs, the strength of non-pecuniary sustainability preferences and by the fraction of capital willing to pay for protection against adverse sustainability shocks. In traditional equity and bond markets, where sustainability-motivated investors account for only a small share of total capital (e.g. Berk and van Binsbergen (2025)), such demand is mechanically diluted, so the associated sustainability risk premium is likely to be quantitatively small and difficult to detect. In markets for sustainability-contingent claims, where sustainable investors are more prevalent, λ has a first-order effect on prices and is empirically identifiable.

Our second contribution is empirical. We connect the theoretical sustainability-contingent claim to the SLB market and develop a dynamic option-pricing framework that allows us to estimate λ from the return dynamics of the embedded contingent component. Since SLBs are conventional bonds whose coupons step up if the issuer fails to meet pre-specified sustainability targets (KPIs) [3]. This feature embeds a put option on sustainability outcomes: investors receive additional cash flows precisely when sustainability performance deteriorates. SLBs therefore map closely into the sustainability-contingent claim in our model. Relative to other green instruments, such as green bonds, SLBs provide a closer empirical proxy because the contingent payoff is explicit, tied to verifiable KPIs. Using institutional holdings data from eMAXX, we further show that sustainable investors are more concentrated in the SLB market than in traditional asset markets, making SLBs a particularly suitable venue for identifying sustainability-motivated pricing.

To take the model to the data, we extend the single-period framework to a dynamic option-pricing model and show how λ governs the value and return dynamics of the sustainability-linked component embedded in SLBs. The valuation of the embedded option component is primarily

[3] A small number of SLBs feature alternative structures, such as coupon step-downs when KPIs are met or early redemption clauses when KPIs are missed. Because these contracts are rare, we focus on the predominant design in which coupons increase when issuers fail to meet sustainability targets.

driven by its hedging value against sustainability performance shortfalls. Empirically, we isolate this component by matching each SLB to a comparable non-SLB issued by the same firm, controlling for duration, coupon rate, credit risk, liquidity, and other standard bond-return determinants, while issuer fixed effects absorb remaining firm-level heterogeneity. This matched-pair design removes conventional bond-pricing components and allows the return differential to identify the sustainability-linked option.

Based on this framework, we estimate a common $\lambda \approx 7.6\%$ using monthly trading returns of 117 matched SLBs between September 2019 and August 2025, drawn from 771 SLBs with available information on returns, liquidity, maturity, and sustainability characteristics. Given the average exposure of the embedded option to sustainability risk and its small weight in total bond value, this estimate implies that investors are willing to forgo approximately 0.55% of expected return at the bond level to hedge sustainability risk, that is, insure against downside sustainability outcomes. The estimate remains robust across alternative specifications, subsamples by issuer region, industry, and KPI type, and when using monthly rather than annual returns.

The third contribution is integrative. Our framework nests the two sustainability-related channels emphasized in the existing literature, the nonpecuniary preference channel and the sustainability risk premium channel, and links them to the same underlying preference parameter and market price of sustainability risk, λ, that govern the SLB pricing. In our model, the expected return on a standard market asset reflects both a non-pecuniary preference channel, under which investors accept lower expected returns for stronger sustainability performance, and a sustainability risk-premium channel, under which investors require compensation for exposure to sustainability shocks. Using our SLB-based estimate of λ to calibrate the model, we show that the two channels largely offset each other in broad equity markets, leaving sustainability-related expected returns differences of only a few basis points. Our calibration allows for correlations between financial and sustainability payoffs, and our conclusion remains similar under different correlation assumptions, helping explain why traditional assets may deliver mixed evidence even when sustainability preferences are present.

Our framework builds on the sustainable asset-pricing models of Pástor et al. (2021), Pedersen et al. (2021), and Avramov et al. (2022). We extend this literature by introducing a sustainability-contingent claim—empirically proxied by sustainability-linked bonds (SLBs)—whose payoff increases when sustainability performance deteriorates. This instrument allows investors to hedge against sustainability performance shortfalls and provides a direct way to identify the sustainability risk premium. We further extend the analysis to a dynamic option-pricing framework that allows us to estimate the market price of sustainability risk, λ, from the return dynamics of the embedded contingent component.

Our paper also contributes to the literature on sustainable investing (Starks, 2023; Hartzmark and Sussman, 2019; Duchin et al., 2025; Inderst and Opp, 2025; Hong et al., 2023b). A central implication of our framework is that the pricing impact of sustainability preferences depends critically on the concentration of sustainable capital in the relevant market. This mechanism is consistent with Berk and van Binsbergen (2025), who show that the sustainability premium embedded in broad equity markets is likely only a few basis points, and sustainability-motivated investors represent a small fraction of aggregate wealth.

Our study also relates to the growing literature on the SLB market. Existing work studies the primary market pricing and optimal contract design at issuance (e.g. Barbalau and Zeni, 2022; Kölbel and Lambillon, 2022; Berrada et al., 2022). Most closely related to our work is Feldhütter et al. (2024), who study SLB pricing using a complementary approach in which the coupon step-up is valued through its triggering probability. They obtain a hedging-related return sacrifice of similar magnitude to ours and find that the SLB label effect—a pricing premium driven by investors' demand for the "green" label rather than by rational exposure to financial or sustainability risks—is negligible. We instead embed the sustainability-linked payoff in an explicit equilibrium pricing framework, emphasizing the hedging role of the contingent claim and the importance of sustainable-capital concentration for the market price of sustainability risk.

More broadly, our work relates to research on sustainability risks in asset pricing. Prior studies show that climate-related risks are priced in equities (Hong et al., 2023a; Bolton and Kacperczyk, 2021; Engle et al., 2020; Sautner et al., 2023a,b; Pankratz et al., 2023), bonds (Seltzer et al., 2025; Goldsmith-Pinkham et al., 2023; Painter, 2020), and options (Kruttli et al., 2025; Ilhan et al., 2021; Cao et al., 2024). Our analysis complements this literature by focusing on the pricing of a sustainability-contingent claim and showing that a new set of instruments, such as SLBs, can hedge a broader set of sustainability risks beyond climate-related targets.

Finally, our evidence of a sizable sustainability risk premium relates to the literature on non-pecuniary preferences. Starks (2023) reviews the distinction between "value" (pecuniary motives) and "values" (non-pecuniary motives) in sustainable investing. Related work estimates preference-driven green premia in bond markets (D'Amico et al., 2025) and studies investors' sustainability attitudes using survey data (Riedl and Smeets, 2017; Bauer et al., 2021; Humphrey et al., 2021; Giglio et al., 2025; Krueger et al., 2020). Our contribution is to provide market-based evidence from the pricing of a sustainability-contingent claim, whose estimated λ captures investors' willingness to pay for insurance against sustainability shortfalls.

The remainder of this paper is organized as follows. We first review the related literature to place our study in context. Section 2 presents a model to establish a theoretical framework for analysis. Section 3 describes the SLB market and the related data features. Section 4 calibrates the model and empirically estimates the sustainability risk premium. The conclusion follows in Section 5.

2 Theoretical Framework

We study the pricing of a sustainability-contingent claim whose financial payoff is negatively related to sustainability performance. The claim delivers higher cash flows when sustainability outcomes deteriorate and therefore provides an explicit hedge against sustainability downturns.

To highlight this hedging channel and its implications for identifying sustainability preferences, we begin with the most parsimonious setting. We consider a single market asset that jointly generates aggregate financial and aggregate sustainability performance, together with the associated sustainability-contingent claim written on the market's sustainability outcome. This one-asset benchmark isolates the core economic mechanism and avoids the additional notation and portfolio-composition issues that arise with multiple risky assets. We discuss the multi-asset case as an extension. The pricing of contingent claim is built based on theoretical framework in (e.g., Pástor et al., 2021; Pedersen et al., 2021; Avramov et al., 2022).

2.1 Sustainability Preference and Asset Payoff

In this economy, there are two types of investors—sustainable and conventional. Each type consists of a continuum of agents who allocate portfolios over their final financial wealth and sustainability performance.

We begin by introducing the preferences of a single sustainable investor, with final wealth denoted by W and sustainable outcomes by X. The utility of this sustainable investor takes an exponential form:

$$U = -\exp(-\gamma W - \eta X), \tag{1}$$

where $\eta > 0$ captures the strength of non-pecuniary preferences. The conventional investor is a special case with $\eta = 0$, caring only about financial returns.

There is a risk-free asset that pays $1 + r_f$ for each dollar invested, as well as two representative risky assets. The first asset represents the aggregate traditional market (the market index), while the second is a *sustainability insurance asset* that proxies the contingent claim payoff. One share of the market index asset delivers a financial payoff v and a sustainability payoff x, representing an abstract measure of sustainability achievement. In other words, investing in the aggregate capital market implicitly inherits firms' sustainability outcomes—for example, their level of carbon emissions. The payoffs of the two risky assets are jointly normally distributed with correlation ρ.

The sustainability insurance asset delivers a financial payoff directly tied to sustainability outcomes, paying βx, where $\beta < 0$. This structure states that the contingent claim provides downside protection by increasing the payoff when sustainability performance x deteriorates. We assume a linear relation in the single-period model and extend it later.

We assume the sustainability insurance asset does not directly contribute to sustainability outcomes. In other words, sustainability improvements can only be achieved through the market index asset, while the insurance asset functions as a derivative instrument that provides financial exposure to sustainability risk without directly influencing the underlying sustainability outcome. This assumption simplifies our analysis, and relaxing it does not affect our characterization of the risk premium, as will be explained later.

We summarize the asset payoffs and mean-variance structure at both the wealth and sustainability level in matrix format. The financial value payoffs are:

$$\boldsymbol{V} = \begin{bmatrix} v \\ \beta x \end{bmatrix}, \quad \boldsymbol{\mu}^v = \mathrm{E}[\boldsymbol{V}] = \begin{bmatrix} \mu_v \\ \beta \mu_x \end{bmatrix}, \quad \boldsymbol{\Sigma}^v = \mathrm{Cov}[\boldsymbol{V}] = \begin{bmatrix} \sigma_v^2 & \beta\rho\sigma_v\sigma_x \\ \beta\rho\sigma_v\sigma_x & \beta^2\sigma_x^2 \end{bmatrix}. \tag{2}$$

The sustainability-level payoff vector is:

$$\boldsymbol{X} = \begin{bmatrix} x \\ 0 \end{bmatrix}, \quad \boldsymbol{\mu}^x = \mathrm{E}[\boldsymbol{X}] = \begin{bmatrix} \mu_x \\ 0 \end{bmatrix}, \quad \boldsymbol{\Sigma}^x = \mathrm{Cov}[\boldsymbol{X}] = \begin{bmatrix} \sigma_x^2 & 0 \\ 0 & 0 \end{bmatrix}. \tag{3}$$

The cross-covariance between value and sustainability payoffs is given by:

$$\boldsymbol{C}^x = \mathrm{Cov}(\boldsymbol{V}, \boldsymbol{X}) = \begin{bmatrix} \rho\sigma_v\sigma_x & 0 \\ \beta\sigma_x^2 & 0 \end{bmatrix}. \tag{4}$$

A distinctive feature of our framework, relative to the existing literature, is that the contingent claim, or the sustainability insurance asset, enables investors to *directly exchange* between the two elements in their utility function specified in equation (1)—financial wealth W and sustainability performance X. The sustainability insurance asset provides explicit financial compensation when sustainability outcomes deteriorate, thereby allowing investors to hedge undesirable realizations of X with adjustments in W. In this sense, this new asset operationalizes a direct market for trading off financial and sustainability utilities.

In contrast, the existing literature (e.g., Pástor et al. (2021); Pedersen et al. (2021); Avramov et al. (2022)) focuses on an *indirect exchange channel*, in which investors deviate from the optimal portfolio based solely on financial payoffs by additionally considering the sustainability characteristics of the assets they hold. In those settings, sustainability enters investor utility only through the composition of their portfolio, but there is no asset that directly compensates for sustainability shortfalls. Our framework fills this gap by introducing a financial instrument that enables a direct exchange between sustainability performance and financial payoffs in equilibrium.

Our setting allows us to examine how the pricing of this contingent claim reveals investors' non-pecuniary preferences and how the availability of such insurance-like instruments reshapes equilibrium in traditional financial markets. In particular, risk aversion to sustainability outcomes—captured by η in equation (1)—induces sustainable investors to demand more hedges of sustainability risks than conventional investors. This elevated demand arises from their desire to hedge against unfavorable sustainability shocks and forms the foundation of the *sustainability risk premium* (SRP). The magnitude of this premium increases with the share of sustainable capital in the economy, as a higher concentration of sustainable investors amplifies the pricing impact of sustainability preferences.

Despite the simplicity of our two-risky-asset framework as an aggregate representation of the broader economy, it admits rich interpretations. At the aggregate level, our framework captures the relative pricing between traditional asset classes and hedging assets that insure against systematic sustainability-related risks. At the firm level, the market index asset and the sustainability insurance asset can be interpreted as a firm's conventional security B_t and its associated coupon step-up claim P_t, respectively. Under this interpretation, the model characterizes their relative pricing behavior and the influence of sustainability preferences on investor demand.

In addition, the structure of our model can be readily extended to a multi-firm setting. The core insights—particularly the transmission of sustainability preferences into asset prices through hedging motives and utility-based demand—remain robust under such generalizations.

2.1.1 Portfolio Allocation Rules of a Single Sustainable Investor

We first consider the optimal portfolio allocation of a single sustainable investor, who is endowed with initial financial wealth W_0 and initial sustainability endowment X_0. This investor maximizes expected utility defined in equation (1), under the assumption of joint normality. It is convenient to interpret portfolio allocation solution in return space and derive a mean–variance portfolio optimization augmented by sustainability risk.

Let $\boldsymbol{p} = \begin{bmatrix} p_1 & p_2 \end{bmatrix}$ denote the price vector, and $\boldsymbol{D}_p = \mathrm{diag}(p_1, p_2)$ the diagonal matrix of asset prices. The investor allocates portfolio weights $\boldsymbol{\omega}$ on the financial return $\boldsymbol{R}_v = \boldsymbol{D}_p^{-1}\boldsymbol{V}$, leading to the following wealth dynamics, $W = W_0\boldsymbol{\omega}^\top\boldsymbol{R}_v$. Similarly, the sustainability payoffs are given by $X = W_0\boldsymbol{\omega}^\top\boldsymbol{D}_p^{-1}\boldsymbol{X} = X_0\frac{W_0}{X_0}\boldsymbol{\omega}^\top\boldsymbol{D}_p^{-1}\boldsymbol{X}$. Based on this dynamic, investing in this portfolio yields a growth rate of sustainability: $\boldsymbol{R}_x = \frac{W_0}{X_0}\boldsymbol{D}_p^{-1}\boldsymbol{X},\ X = X_0\boldsymbol{\omega}^\top\boldsymbol{R}_x$. The ratio $\frac{W_0}{X_0}$ scales the portfolio investment W_0 relative to the sustainability endowment X_0 and adjusts the growth rate $\boldsymbol{R}_x$ to a unitless measure.

The financial return $\boldsymbol{R}_v$ and the sustainability growth $\boldsymbol{R}_x$ are payoffs scaled by price and by the unit translator $\frac{W_0}{X_0}$. Both follow a joint normal distribution, with mean–variance structure specified as $\boldsymbol{\mu}_R^v = \boldsymbol{D}_p^{-1}\boldsymbol{\mu}^v,\ \boldsymbol{\Sigma}_R^v = \boldsymbol{D}_p^{-1}\boldsymbol{\Sigma}^v\boldsymbol{D}_p^{-1},\ \boldsymbol{\mu}_R^x = \frac{W_0}{X_0}\boldsymbol{D}_p^{-1}\boldsymbol{\mu}^x,\ \boldsymbol{\Sigma}_R^x = \left(\frac{W_0}{X_0}\right)^2\boldsymbol{D}_p^{-1}\boldsymbol{\Sigma}^x\boldsymbol{D}_p^{-1}$. The cross-covariance in return space is $\boldsymbol{C}_R^x = \mathrm{Cov}(\boldsymbol{R}_v, \boldsymbol{R}_x) = \frac{W_0}{X_0}\boldsymbol{D}_p^{-1}\boldsymbol{C}^x\boldsymbol{D}_p^{-1}$. Based on these matrices in return space, the investor's optimization problem is equivalent to maximizing the following mean–variance objective:

$$\tilde{U}(\boldsymbol{\omega}) = \boldsymbol{\omega}^\top \left(\boldsymbol{\mu}_R^v - R_f \cdot \mathbf{1} + \frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\mu}_R^x \right) - \frac{1}{2} \tilde{\gamma} \boldsymbol{\omega}^\top \boldsymbol{\Sigma}_R^v \boldsymbol{\omega} - \frac{1}{2} \frac{\tilde{\eta}^2}{\tilde{\gamma}} \boldsymbol{\omega}^\top \boldsymbol{\Sigma}_R^x \boldsymbol{\omega} - \frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\omega}^\top \boldsymbol{C}_R^x \boldsymbol{\omega}. \tag{5}$$

Here, $\tilde{\gamma} = W_0 \gamma$ and $\tilde{\eta} = X_0 \eta$ denote the relative risk aversion coefficients scaled to the financial and sustainability return units, respectively. The return-space matrices mirror the structure of their payoff-space counterparts.

The investor's utility reflects a two-dimensional concern for both financial wealth and sustainability performance. This introduces an additional risk channel, represented by the covariance term $\frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\omega}^\top \boldsymbol{C}_R^x \boldsymbol{\omega}$, which links fluctuations in financial and sustainability outcomes. Together, these extensions distort the standard mean–variance optimization and yield the following augmented portfolio choice for a sustainable investor:

$$\boldsymbol{\omega}_s = \tilde{\gamma}^{-1} \left(\boldsymbol{\Sigma}_R^v + \frac{\tilde{\eta}^2}{\tilde{\gamma}^2} \boldsymbol{\Sigma}_R^x + \frac{2\tilde{\eta}}{\tilde{\gamma}^2} \boldsymbol{C}_R^x \right)^{-1} \left(\boldsymbol{\mu}_R^v - R_f \cdot \mathbf{1} + \frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\mu}_R^x \right). \tag{6}$$

2.1.2 Differential Participation of Sustainable Investors across Markets

To describe equilibrium pricing, we now move from the portfolio problem of a single sustainable investor to market-level wealth masses. There are two types of investors—sustainable and conventional. We assume that all sustainable investors share the same relative preference parameters $(\tilde{\gamma}, \tilde{\eta})$ and therefore follow the same portfolio rule in (6). This homogeneity simplifies aggregation and does not alter the model's core objective: to understand how the concentration of sustainable capital shapes the market price of sustainability risk.

A conventional investor's portfolio rule is the nested case with $\tilde{\eta} = 0$, which yields the classical mean–variance allocation:

$$\boldsymbol{\omega}_c = \tilde{\gamma}^{-1} \left(\boldsymbol{\Sigma}_R^v \right)^{-1} \left(\boldsymbol{\mu}_R^v - R_f \cdot \mathbf{1} \right). \tag{7}$$

Without loss of generality, we assume that all conventional investors share the same relative risk aversion coefficient $\tilde{\gamma}$. These assumptions are introduced solely to remove unnecessary scale constants and to allow us to aggregate individual demands within each investor type.

A key ingredient of our framework is *differential participation of sustainable investors* across the two risky-asset markets. Empirically, sustainability-motivated investors represent only a small fraction of aggregate market wealth, implying limited pricing impact in broad, traditional markets. At the same time, a sustainability-hedge instrument—a contingent claim that pays off when sustainability performance deteriorates—can attract a different investor clientele because it offers a direct and contractible hedge against sustainability downturns. Motivated by this logic, we allow the composition of active investors to differ between the traditional asset market and the market for the sustainability hedge claim.

We formalize market segmentation as follows. Let $m \in \{1, 2\}$ index the two risky-asset markets, where $m = 1$ denotes the traditional (index) asset and $m = 2$ denotes the sustainability hedge claim (the contingent claim). For each market m, let$W_{s,0}^{(m)}, \quad W_{c,0}^{(m)}$ denote the total initial financial wealth of sustainable and conventional investors who are actively trading in that market. Define the corresponding sustainable-capital share as

$$\theta_{s,m} = \frac{W_{s,0}^{(m)}}{W_{s,0}^{(m)} + W_{c,0}^{(m)}} \in (0, 1), \qquad m = 1, 2. \tag{8}$$

Here, $\theta_{s,1}$ is the fraction of sustainable capital among investors who trade the traditional asset, while $\theta_{s,2}$ is the analogous share among investors who trade the sustainability hedge claim.

Consistent with evidence that sustainability-motivated investors constitute only a small share of overall market wealth (e.g., Berk and van Binsbergen (2025)), we interpret $\theta_{s,1}$ as being close to zero. In contrast, because the hedge claim delivers explicit financial compensation in bad sustainability states, it can draw disproportionately more sustainable participation and/or face limited participation by conventional investors, implying $\theta_{s,2} > \theta_{s,1}$. Intuitively, sustainable investors have stronger hedging demand for this claim, whereas conventional investors may have weaker incentives or face institutional frictions to trade it, generating a pronounced wedge between $\theta_{s,1}$ and $\theta_{s,2}$. In the empirical section, we use Sustainability-Linked Bonds (SLBs) as a traded proxy for the sustainability hedge claim and document that this wedge is indeed large in the data, with $\theta_{s,2}$ sharply exceeding $\theta_{s,1}$.

We provide a more detailed discussion of solving for equilibrium price in Appendix A. The solution highlights the distinct roles of $\theta_{s,1}$ and $\theta_{s,2}$ in shaping expected returns across the traditional market and the sustainability hedge market.

2.2 Sustainability Risk Premium and Pricing of Sustainability Contingent Claim

The resulting expected-return expression allows us to separate the sustainability risk premium from standard financial compensation and to identify preference parameters that capture non-pecuniary motives. Conceptually, the structure parallels the CAPM: expected returns compensate investors for bearing systematic risk. In our case, the non-tradable sustainability outcome X and investors' aversion to adverse sustainability realizations—captured by $\tilde{\eta}$ in equation (1)—introduce an additional source of priced risk. Only sustainable investors with $\tilde{\eta} > 0$ assign value to fluctuations in X, so the magnitude of this sustainability premium depends on their relative market shares, $\theta_{s,1}$ and $\theta_{s,2}$.

Solving the market-clearing condition yields equilibrium prices and, equivalently, expected returns in return space. Investors allocate wealth across two assets that load differently on financial and sustainability dimensions:

$$\boldsymbol{R}_v = \begin{bmatrix} r_v \\ \beta r_x \end{bmatrix}, \qquad \boldsymbol{R}_x = \begin{bmatrix} r_x \\ 0 \end{bmatrix},$$

where $r_v \sim N(\tilde{\mu}_v, \tilde{\sigma}_v^2)$ denotes the financial return, and $r_x \sim N(\tilde{\mu}_x, \tilde{\sigma}_x^2)$ is the growth rate of sustainability outcomes. The two shocks are jointly normal with correlation ρ. To indicate return-level quantities, we use tildes for scalars (e.g., $\tilde{\mu}_v$, $\tilde{\sigma}_v$) and subscript R for matrices.

The complete derivation is provided in Appendix A. Here we summarize the key equilibrium implication for the sustainability-contingent hedge claim (Asset 2), presented in the following proposition.

Proposition 1 (Expected returns of the sustainability-contingent claim)**.** *If the economy consists of two types of investors following the optimal portfolio allocation rules in equations* (6) *and* (7)*, and let* $\theta_{s,1}$ *and* $\theta_{s,2}$ *be the wealth ratios of sustainable investors in the two asset markets as defined in equation* (8)*, then the expected excess return of the sustainability-contingent hedge claim is:*

$$\tilde{\mu}_2 - R_f = \omega_1 \beta \lambda + \omega_2 \tilde{\gamma} \beta^2 \tilde{\sigma}_x^2 \approx \beta \lambda. \tag{9}$$

where

$$\lambda = \lambda_x + \lambda_v, \tag{10}$$

denotes the market price of sustainability risk faced by the hedge claim, which decomposes into a sustainability component,

$$\lambda_x = \theta_{s,2}\, 2\tilde{\eta}\tilde{\sigma}_x^2, \tag{11}$$

and a traditional co-movement component,

$$\lambda_v = \tilde{\gamma}\rho\tilde{\sigma}_v\tilde{\sigma}_x. \tag{12}$$

$\omega_1 \approx 1$ *and* $\omega_2 \approx 0$ *are the market-value weights of the two assets.*

The market–value weights ω_1 and ω_2 reflect each asset's contribution to aggregate priced risk, that is, to economy-wide fluctuations along the two dimensions of financial wealth and sustainability outcomes. A larger market weight amplifies an asset's role in equilibrium compensation, while a smaller weight renders its contribution second order. In our theoretical benchmark, Asset 2 is derivative-like by construction—its market value is negligible relative to the aggregate market—so ω_2 is close to zero. As a result, the term $\omega_2\tilde{\gamma}\beta^2\tilde{\sigma}_x^2$ in (9), representing the hedge claim's own stand-alone financial-variance contribution, is economically negligible. The expected excess return of the sustainability-contingent hedge claim can thus be approximated by a single-factor specification,

$$\tilde{\mu}_2 - R_f \approx \beta\lambda.$$

This factor representation offers several insights that guide our theoretical interpretation and empirical implementation. First, the equilibrium expected return of the sustainability-contingent hedge claim is dominated by its hedging role against the market-index asset. The first term in (9), $\beta\lambda$, reflects how the hedge payoff offsets fluctuations in the market index along both the financial and sustainability dimensions. The market price of sustainability risk, λ, decomposes into two components,

$$\lambda = \lambda_x + \lambda_v,$$

where λ_x captures the sustainability risk premium and λ_v captures the traditional co-movement component.

The sustainability risk premium λ_x arises from the insurance role of the hedge claim in smoothing adverse sustainability shocks. When aggregate sustainability performance deteriorates ($r_x \downarrow$), the hedge payoff βr_x increases, providing financial compensation that stabilizes investors' utility. Under CARA preferences defined over both financial wealth W and sustainability performance X, the sustainability component is

$$\lambda_x = \theta_{s,2}\big(2\,\tilde{\eta}\,\tilde{\sigma}_x^2\big),$$

as shown in (11). Economically, only sustainable investors ($\tilde{\eta} > 0$) value this channel, so λ_x scales with their effective market influence $\theta_{s,2}$. A higher concentration of sustainable capital ($\theta_{s,2} \uparrow$) or stronger sustainability risk aversion ($\tilde{\eta} \uparrow$) therefore increases λ_x and, given $\beta < 0$, lowers the expected return on the hedge claim.

The second component represents the traditional co-movement channel,

$$\lambda_v = \tilde{\gamma}\,\rho\,\tilde{\sigma}_v\,\tilde{\sigma}_x,$$

which arises from the covariance between financial payoffs (r_v) and sustainability shocks (r_x). Its magnitude depends on the correlation ρ between these two dimensions. When $\rho = 0$, financial and sustainability shocks are orthogonal and this channel vanishes—leaving $\lambda = \lambda_x$, so the hedge claim prices only sustainability risk. When $\rho \neq 0$, the hedge payoff covaries with financial wealth through the r_v–r_x linkage, generating an additional, albeit typically smaller, component in λ.

In summary, the equilibrium expression (9) implies that the sustainability-contingent hedge claim provides a direct estimate of the market price of sustainability risk, λ. This total price of risk can be decomposed into the sustainability component λ_x and the co-movement component λ_v. In equilibrium, λ_x is the dominant source of variation when sustainable capital is concentrated in the hedge-claim market, while λ_v becomes quantitatively relevant only when the correlation ρ between financial and sustainability payoffs is sufficiently large.

The same two channels that determine λ also shape the pricing of the traditional market index, so both enter its expected return. To make this link transparent, we focus on the derivative-like benchmark in which $\omega_1 = 1$ and $\omega_2 = 0$, and summarize the resulting factor presentation in the following proposition.

Proposition 2 (Factor presentation of expected returns)**.** *If the economy consists of two types of* *investors following the optimal portfolio allocation rules in equations (6) and (7), and the wealth ratios of sustainable capital in the two asset markets are given by $\theta_{s,1}$ and $\theta_{s,2}$ as defined in equation (8), then setting $\omega_1 = 1$ and $\omega_2 = 0$ yields the following sustainability–factor representation of expected returns:*

$$\tilde{\mu}_2 - R_f = \beta\lambda, \tag{13}$$

where the market price of sustainability risk λ consists of two components:

$$\lambda = \lambda_x + \lambda_v, \qquad \lambda_x = \theta_{s,2}\, 2\tilde{\eta}\tilde{\sigma}_x^2, \qquad \lambda_v = \tilde{\gamma}\rho\tilde{\sigma}_v\tilde{\sigma}_x.$$

The sustainability component λ_x reflects investors' aversion to sustainability risks, while the co-movement component λ_v arises from the covariance between financial and sustainability payoffs. The same two channels enter the expected return of the market index asset:

$$\tilde{\mu}_1 - r_f = \underbrace{-\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\tilde{\mu}_x}_{\textit{non-pecuniary preference reward}} + \underbrace{\frac{1}{2}\frac{\theta_{s,1}}{\theta_{s,2}}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_x}_{\textit{sustainability risk premium}} + \underbrace{2\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_v + \tilde{\gamma}\tilde{\sigma}_v^2}_{\textit{traditional risk premium}}. \tag{14}$$

The result in Proposition 2 shows that the expected return of the market index also consists of two components: a traditional risk premium and a sustainability-related component. The sustainability component itself reflects two offsetting forces that together determine the net sustainability effect on the market index.

The first force is the *non-pecuniary preference reward*, analogous to the mechanism highlighted in Pástor et al. (2021). Because investment in the market index benefits from expected improvements in sustainability outcomes, sustainable investors are willing to pay a higher price for this asset, which translates into a lower expected return. This effect is captured by the term $-\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\tilde{\mu}_x$ in equation (14), representing a negative premium consistent with investors' willingness to sacrifice financial return for sustainability gains. The term $\frac{\tilde{\eta}}{\tilde{\gamma}}$ translates the impact of the non-tradable sustainability outcome into the pricing of financial returns, linking the utility value of sustainability to observable market prices.

The second force is the *sustainability risk premium*, arising from investors' aversion to uncertainty in sustainability outcomes. The term $\frac{1}{2}\frac{\theta_{s,1}}{\theta_{s,2}}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_x$ reflects compensation for bearing sustainability risk: when investors care about sustainability performance ($\tilde{\eta} > 0$), they require a higher expected return for holding assets exposed to adverse sustainability shocks. The magnitude of this effect depends on the share of sustainable capital in the traditional market, $\theta_{s,1}$, which scales how strongly sustainability preferences influence pricing.

Although the two terms in equation (14) can each be sizable depending on the parameter values, they naturally offset one another. The non-pecuniary preference reward lowers expected returns as investors value positive sustainability outcomes, while the sustainability risk premium raises expected returns as investors demand compensation for exposure to sustainability shocks. Their opposing directions can result in a very small net sustainability effect on the market index, even when both channels are individually strong.

Moreover, both effects are scaled by the sustainable capital share $\theta_{s,1}$. When sustainable investors represent only a small portion of total market wealth, the overall influence of sustainability preferences on pricing becomes even weaker. Together, the offsetting nature of the two forces and the small magnitude of $\theta_{s,1}$ explain why detecting sustainability effects in aggregate market returns is empirically difficult, reinforcing the importance of examining markets where sustainable capital is more concentrated.

The traditional risk premium in equation (14) consists of two parts. The first, $\tilde{\gamma}\tilde{\sigma}_v^2$, reflects the standard financial risk compensation driven by the variance of the market index payoff. The second arises from the covariance between financial and sustainability payoffs, captured by $\lambda_v = \tilde{\gamma}\rho\tilde{\sigma}_v\tilde{\sigma}_x$. This covariance makes the market index more exposed to joint fluctuations in wealth and sustainability, producing the constant factor of two in (14). Since this interaction affects both financial and sustainability utility, λ_v is indirectly influenced by $\tilde{\eta}$ through the co-movement of r_v and r_x.

Our framework is related to Avramov et al. (2022) in that both allow sustainability considerations to command a risk premium, but the empirical objects differ. Avramov et al. (2022) test the equity *cross section* using firm-level ESG scores to explain return differences across stocks. By contrast, we study sustainability-contingent payoffs that are explicitly linked to contractible performance targets, so sustainability enters contractually rather than through composite scores. This contractual linkage lets us read the market price of sustainability risk directly from an insurance-style payoff, yielding a $\beta\lambda$ representation aligned with option-pricing intuition.

From a methodological perspective, solving for equilibrium under stochastic sustainability outcomes is analytically complex. Sustainable investors perceive a covariance structure that differs from that of conventional investors, which complicates the process of deriving equilibrium prices from the market-clearing condition. While Avramov et al. (2022) provide a general solution for this stochastic environment, our objective is to isolate how variations in sustainable capital concentration (θ) affect equilibrium pricing. To this end, we adopt a linear-approximation approach that produces a tractable and interpretable relationship between θ and equilibrium asset prices, as detailed in Appendix A.

2.3 Pricing of Sustainability-Contingent Claims as Put Options

The single-period equilibrium framework highlights the role of the market price of sustainability risk, λ, and shows how a sustainability-contingent hedge claim can provide a clean test of sustainability preferences through its $\beta\lambda$ pricing structure. Since this hedge claim is derivative-like and is intended to insure against sustainability downturns, it is natural to extend the analysis to a continuous-time, no-arbitrage environment. Doing so allows for dynamic pricing and option-like, state-contingent cash flows, and provides a representation that can be mapped directly to traded empirical proxies with observable secondary-market prices.

To closely connect the theory to our empirical setting, we model the sustainability-contingent hedge component as a binary put-style payoff written on sustainability performance. Let P_t denote the time-t value of the sustainability-linked hedge component, with evaluation date T. The payoff is

$$P_T = \begin{cases} Sp, & x_T < K, \\ 0, & x_T \geq K, \end{cases} \tag{15}$$

where x_T is the realized sustainability performance at T, K is a contractible KPI threshold, and Sp is the payment triggered upon underperformance. In our empirical application to SLBs, Sp corresponds to the discounted value of all additional coupon step-up payments specified in the contract. To price this sustainability put option, we adopt a standard no-arbitrage approach, which can accommodate a broad class of alternative option payoffs. We focus on the binary structure because it closely mimics the coupon step-up design and provides the tightest link between the model's objects and observed prices.

2.3.1 No-arbitrage pricing of the sustainability put component

Building on the single-period model, equation (13) implies that the expected return of the sustainability-contingent hedge claim follows a factor structure, where $\lambda = \lambda_x + \lambda_v$ reflects both the sustainability component and the traditional co-movement component arising from correlation ρ. In continuous time, we model the financial payoff v_t and the sustainability performance x_t as correlated Geometric Brownian Motions:

$$\frac{dv_t}{v_t} = \tilde{\mu}_v\, dt + \tilde{\sigma}_v\, dB_t^v, \qquad \frac{dx_t}{x_t} = \tilde{\mu}_x\, dt + \tilde{\sigma}_x\, dB_t^x, \tag{16}$$

where $\tilde{\mu}_v, \tilde{\mu}_x$ and $\tilde{\sigma}_v, \tilde{\sigma}_x$ denote expected growth rates and volatilities, and the two Brownian motions satisfy $\mathrm{Corr}(dB_t^v, dB_t^x) = \rho$.

We assume the existence of a standard pricing kernel under the risk-neutral measure:

$$\frac{d\pi_t}{\pi_t} = -r_f\, dt - a_v\, dB_t^v - a_x\, dB_t^x, \tag{17}$$

where a_v and a_x are the market prices of financial and sustainability risk, respectively.

Under the assumption that the sustainability-contingent step-up feature does not alter the issuer's default risk, the hedge component P_t can be priced independently of the baseline bond payoff. Its value is

$$P_t = \mathbb{E}_t^Q\big[1_{\{x_T<K\}}\big] \cdot Sp \cdot e^{-r_f(T-t)}, \tag{18}$$

where r_f is the constant risk-free rate. Detailed derivations are provided in Appendix B; here we summarize the main pricing results.

Proposition 3 (Pricing and conditional factor representation of the sustainability-contingent hedge component)**.** *The price of the sustainability step-up component in equation* (18) *is*

$$P_t = Sp \cdot e^{-r_f(T-t)} \cdot N(-e_t), \tag{19}$$

where

$$e_t = \frac{\ln(x_t/K) + (\tilde{\mu}_x - \lambda)(T-t) - \frac{1}{2}\tilde{\sigma}_x^2(T-t)}{\tilde{\sigma}_x\sqrt{T-t}}. \tag{20}$$

According to the pricing kernel in equation (17), the market price of sustainability risk relevant for the hedge component is

$$\lambda = -Cov\left(\frac{dx_t}{x_t}, \frac{d\pi_t}{\pi_t}\right) = a_x\tilde{\sigma}_x + a_v\tilde{\sigma}_x\rho, \tag{21}$$

combining the sustainability and financial channels through ρ*.*

The excess expected return of the step-up component P_t *satisfies*

$$\frac{dP_t}{P_t} - r_f\,dt = \beta_t(\lambda)\left(\lambda\,dt + \tilde{\sigma}_x\,dB_t\right), \tag{22}$$

and the conditional expected return is

$$\mathbb{E}_t\left[\frac{dP_t}{P_t}\right] - r_f\,dt = \beta_t(\lambda)\,\lambda\,dt, \tag{23}$$

where dB_t *denotes the Brownian innovation associated with sustainability shocks. The conditional sustainability factor loading* $\beta_t(\lambda) = \frac{\partial P_t}{\partial x_t}\frac{x_t}{P_t}$*, derived from equation (19), simplifies to*

$$\beta_t(\lambda) = \frac{n(e_t)}{N(e_t)} \cdot \frac{-1}{\tilde{\sigma}_x\sqrt{T-t}} < 0, \tag{24}$$

where $n(\cdot)$ *and* $N(\cdot)$ *denote the standard normal density and cumulative distribution functions.*

2.3.2 Linking No-Arbitrage Option Pricing to the One-Period Benchmark

The continuous-time specification mirrors the equilibrium structure of the single-period model. Equation (23) retains the same conditional factor form, $\mathbb{E}_t[dP_t/P_t] - r_f dt = \beta_t(\lambda)\lambda dt$, but now with a time-varying exposure $\beta_t(\lambda)$ determined by option features such as time to evaluation, moneyness, and KPI feasibility. The dependence of β_t on λ introduces a nonlinear mapping between the market price of sustainability risk and observed prices and returns, which captures the option-like payoff embedded in sustainability-contingent contracts and provides a realistic foundation for empirical estimation.

Under the no-arbitrage framework above, the market price of sustainability risk is pinned down by the parametric pricing kernel in equation (17). The loading coefficients a_x and a_v determine the market prices of sustainability and financial risk, respectively, and imply

$$\lambda = a_x \tilde{\sigma}_x + a_v \tilde{\sigma}_x \rho.$$

This representation is convenient for valuation, but on its own it does not identify the economic forces that determine (a_x, a_v) and hence λ.

Our one-period benchmark provides this economic interpretation. As detailed in Appendix B, under mild regularity conditions, the pricing logic of the one-period model can be embedded in the continuous-time pricing environment, yielding the same market price of sustainability risk:

$$\lambda = \theta_{s,2}\, 2\tilde{\eta}\, \tilde{\sigma}_x^2 + \tilde{\gamma}\, \rho\, \tilde{\sigma}_v\, \tilde{\sigma}_x.$$

The first term captures the sustainability component driven by the interaction of sustainable-capital concentration $\theta_{s,2}$, sustainability risk aversion $\tilde{\eta}$, and sustainability volatility $\tilde{\sigma}_x^2$. The second term reflects the traditional co-movement component arising from cross-dimensional covariance. This mapping unifies the reduced-form option-pricing object λ with preference heterogeneity and segmented participation in the market for sustainability-contingent hedge claims.

We denote the conditional expected return of the sustainability-contingent hedge component as the contingent-claim risk premium $\mathcal{F}_t$ and summarize the implication below.

Proposition 4 (Risk premium in sustainability-contingent claims and economic determinants)**.** *Given the market price of sustainability risk*

$$\lambda = \theta_{s,2}\, 2\tilde{\eta}\tilde{\sigma}_x^2 + \tilde{\gamma}\rho\tilde{\sigma}_v\tilde{\sigma}_x$$

as implied by the one-period benchmark, the conditional risk premium of the sustainability-contingent hedge component satisfies

$$\mathcal{F}_t = \mathbb{E}_t\left[\frac{dP_t}{P_t}\right] - r_f\, dt = \beta_t(\lambda) \cdot \lambda\, dt. \tag{25}$$

Moreover, since $\beta_t(\lambda) < 0$, the risk premium becomes more negative as sustainable capital concen-

tration or sustainability risk aversion increases:

$$\frac{\partial \mathcal{F}_t}{\partial \theta_{s,2}} < 0, \qquad \frac{\partial \mathcal{F}_t}{\partial \tilde{\eta}} < 0.$$

Intuitively, higher sustainable capital concentration or stronger sustainability risk aversion implies greater demand for insurance against adverse sustainability outcomes, leading to a higher put-option value and a more negative expected return on the sustainability-contingent hedge component. In the empirical analysis, we use SLB step-up structures as a traded proxy for this contingent claim and exploit their secondary-market prices to estimate λ and the implied strength of sustainability-insurance motives.

2.3.3 Multiple-Firm Extension

So far, we have focused on an aggregate sustainability outcome and a representative sustainability-contingent hedge claim written on that aggregate outcome. This parsimonious setup isolates the key mechanism—how the market price of sustainability risk, λ, is revealed by a derivative-like hedge payoff. In empirical applications, however, we observe a cross section of firms, each associated with its own sustainability dynamics and its own sustainability-contingent claim. The same pricing logic extends naturally to this multi-firm environment.

Formally, let firm i have sustainability performance $x_t(i)$ evolving as

$$\frac{dx_t(i)}{x_t(i)} = \tilde{\mu}_x(i)\,dt + \tilde{\sigma}_x(i)\,dB_t^x(i). \tag{26}$$

Pricing is governed by a common stochastic discount factor that loads on the systematic sustainability factor. The firm-level price of sustainability risk, $\lambda(i)$, is therefore pinned down by how firm i's sustainability growth co-moves with the systematic fluctuation embedded in the pricing kernel,

$$\lambda(i) = -\mathrm{Cov}\left(\frac{dx_t(i)}{x_t(i)}, \frac{d\pi_t}{\pi_t}\right). \tag{27}$$

Details of the pricing kernel specification and the resulting valuation formulas are provided in Appendix B.

Accordingly, the sustainability-contingent component $P_t(i)$ satisfies

$$\frac{dP_t(i)}{P_t(i)} - r_f\, dt = \beta_{i,t}(\lambda(i)) \cdot (\lambda(i)\, dt + \tilde{\sigma}_x(i)\, dB_t^x(i)), \tag{28}$$

where $\beta_{i,t}(\lambda(i)) = \frac{\partial P_t(i)}{\partial x_t(i)} \frac{x_t(i)}{P_t(i)}$ is the (state-dependent) sustainability loading implied by firm i's dynamics and the contingent-claim payoff. Specifically,

$$\beta_{i,t}(\lambda(i)) = \frac{n(e_t(i))}{N(e_t(i))} \cdot \frac{-1}{\tilde{\sigma}_x(i)\sqrt{T-t}} < 0, \tag{29}$$

where

$$e_t(i) = \frac{\ln(x_t(i)/K(i)) + (\tilde{\mu}_x(i) - \lambda(i))\,(T(i) - t) - \frac{1}{2}\tilde{\sigma}_x(i)^2(T(i) - t)}{\tilde{\sigma}_x(i)\sqrt{T(i) - t}}. \tag{30}$$

3 Introduction of SLB and Stylized Facts

Guided by our theoretical framework for sustainability-contingent claims, we now introduce the market for Sustainability-Linked Bonds (SLBs) and document key stylized facts. These features suggest that SLBs provide a close empirical proxy for the sustainability-contingent claim in our model and allow us to estimate the market price of sustainability risk from SLB prices.

The market for SLBs began to emerge in 2019 and reached its peak issuance in 2022, totaling USD 76 billion (13.64% of global green bond issuance). Issuance moderated to USD 66 billion in 2023.[4] While growing rapidly, SLBs remain small relative to global capital markets: global equity markets were valued at USD 115 trillion in 2023, and the fixed-income universe comprised USD 140.7 trillion in outstanding debt with USD 25.2 trillion in new issuance, including USD 7.7 trillion in global bond issuance.[5]

Figure 3 shows the distribution of SLB issuers by industry and geographic region. Among the 771 SLBs retrieved from Bloomberg as of November 2023, 536 (69.25%) are issued by firms in the producing sector, 104 (13.44%) by government-related entities, 83 (10.72%) by utilities, and 51 (6.59%) by financial institutions. Geographically, 513 SLBs (66.28%) originate from Europe, 132

[4]See https://www.environmental-finance.com/content/the-green-bond-hub/resilience-innovation-and-reinvention-the-sustainable-bond-market-in-2025.html

[5]See https://www.spglobal.com/ratings/en/regulatory/article/250131-global-financing-conditions-a-mixed-picture-as-uncertainty-builds-but-the-issuance-forecast-remains-positiv-s13397963

(17.05%) from Asia, 50 (6.46%) from North America, and the remaining 79 (10.21%) from other regions—consistent with Starks (2023); Dyck et al. (2019), who document Europe as the most developed market for sustainable investments.

As a benchmark, we collect all 9721 conventional bonds issued by SLB issuers from Bloomberg. We focus on the secondary market, where both pricing and institutional holdings provide information about SLB valuation and sustainability performance. Table 1 highlights systematic differences between SLBs and non-SLBs: SLBs typically have lower coupons, shorter maturities, smaller issuance sizes, and lower credit ratings. In this paper, we treat these issuance-stage differences as given and focus on pricing dynamics in the secondary market to recover investors' non-pecuniary preferences. Theoretical and empirical discussions of issuance incentives appear in Barbalau and Zeni (2022); Berrada et al. (2022); Feldhütter et al. (2024); Mielnik and Erlandsson (2022).

3.1 Coupon Step-up Contingent on Sustainability Goals' Outcome

SLBs incorporate explicit financial penalties when issuers fail to meet predefined sustainability performance targets. More than 80% of these penalties take the form of coupon step-ups,[6] directly linking investor cash flows to sustainability KPIs. For SLBs with such contingent coupons, the payoff can be viewed as comprising two components: a standard corporate bond and a sustainability-contingent insurance claim. The KPI is evaluated at a specified date T, typically around the midpoint of maturity.

As an illustration, Figure 1 reports the structure of an SLB issued by ENEL FINANCE INTEL NV. The firm committed to reducing greenhouse gas emissions below 148G/KWHEQ by December 31, 2023; failure triggers a 25bps coupon step-up. ENEL did not meet the target, incurring an additional interest cost of USD 27 million—roughly 2.5% of its 2024 interest expense.[7]

Figure 2 summarizes KPI types across our sample. More than 70% are climate-related, including GHG emissions, CO_2 emissions, renewable energy metrics, fossil-fuel efficiency, and green-asset measures. The remaining KPIs span broader ESG indicators such as water usage, waste management, diversity, employee safety, and SDG-linked income.

SLBs differ fundamentally from green, social, and sustainability bonds that rely on "use of pro-

[6] Other penalty types include early redemption, over-redemption, and issuer-level sustainability investments.
[7] See https://anthropocenefii.org/slb/enel-slbs-update-on-2023-observation-date.

ceeds." The latter require issuers to commit to how bond proceeds will be spent—a non-standard, weakly monitored, and difficult-to-verify condition that raises concerns about comparability and greenwashing.[8] In contrast, SLBs tie contractible financial consequences directly to verifiable sustainability outcomes, making their payoff structure substantially more transparent and economically meaningful for pricing.

3.2 Separate a Sustainability Put Option from SLB

The contingent coupon structure naturally yields a decomposition:

$$SLB_t = BD_t + P_t, \tag{31}$$

where BD_t is the value of the standard corporate bond and P_t is the value of the sustainability-linked insurance. The payoff of the insurance component is a binary put specified in equation (15):

$$P_T = \begin{cases} Sp, & x_T < K, \\ 0, & x_T \geq K, \end{cases}$$

where Sp is the discounted value of all additional coupon payments triggered at evaluation date T. In practice, coupon step-ups are paid semi-annually or annually and may feature multiple observation dates. For tractability, we abstract from interim default and from multiple check dates, and treat Sp as a single, one-time payment at the evaluation date T. This simplification does not affect our main pricing implication—the conditional factor structure $\beta_t(\lambda)\lambda$—which continues to hold under richer payment schedules. It does, however, yield a more tractable expression for $\beta_t(\lambda)$.

Economically, the step-up behaves like a put option on sustainability performance: it pays only when the issuer underperforms relative to the KPI. Thus, P_t provides explicit insurance against sustainability shortfalls and reveals investors' willingness to hedge downside sustainability risks.

A key empirical advantage is that P_t represents only a small fraction of total bond value. Figure 4 shows that the average step-up is 18.83bps and the average time to evaluation is 7.23

[8] "Greenwashing" refers to firms portraying themselves as environmentally responsible while taking limited substantive action; see Flammer (2021).

years (Table 1). Under a risk-free rate $r_f = 2\%$, the present value of the step-up is:

$$Sp = 0.1883\% \cdot \frac{1 - e^{-2\% \cdot 7.23}}{2\%} \approx 1.28\%.$$

This magnitude—roughly 1.28% of par—is too small to materially alter credit risk or BD_t's pricing. Our empirical calibrations confirm that default-related pricing is effectively unchanged, validating the separability assumption in (31).

This decomposition allows us to treat P_t as a distinct asset that isolates the sustainability-risk component of the SLB price. Because its payoff depends only on sustainability underperformance, P_t serves as a clean measurement instrument for investors' non-pecuniary preferences.

To implement this decomposition empirically, we must recover an appropriate proxy for BD_t. Following Flammer (2021), we match each SLB to the most comparable non-SLB issued by the same firm using the Mahalanobis distance.[9] Matching variables include: (i) issuance amount, (ii) maturity, (iii) coupon rate, and (iv) issuance-date difference, supplemented by (v) Bloomberg bond rating to capture credit-quality differences documented in Table 1. This procedure yields 499 matched SLBs and 362 matched non-SLBs, providing a firm-specific benchmark for the conventional bond component.

3.3 Stylized Facts about the SLB Market

Utilizing the granular bond-holding data from eMAXX, we further analyze whether sustainable investors and conventional investors behave differently in SLB markets. We draw on quarterly institutional bond-holding records from eMAXX and consider several definitions of sustainable investors.

We begin with signatories of the Principles for Responsible Investment (PRI) as our benchmark.[10] PRI is the largest global initiative promoting responsible investing, with over 5,000 signatories representing $139.6 trillion in assets under management as of November 2025. Its scale makes it a natural starting point for identifying sustainable institutions. However, its breadth also implies substantial heterogeneity—mandates vary, enforcement is minimal, and disclosure is

[9] Mahalanobis distance accounts for cross-variable covariance, ensuring comparable joint distributions across matched bonds.

[10] Institutional names and domiciles are matched to PRI signatories through fuzzy matching and manual verification.

voluntary—making the classification coarse.

To obtain a sharper measure, we follow Gibson Brandon et al. (2022) and restrict attention to PRI signatories that (i) are classified as Investment Managers and (ii) appear in our data only after their PRI sign-up date. This "PRI-narrow" group better isolates institutions with clearer mandates and a more credible commitment to sustainability integration.

Finally, motivated by earlier evidence that Europe hosts a disproportionately large share of sustainable capital (Starks, 2023; Dyck et al., 2019), we construct a third proxy based on investor domicile. While not a direct measure of sustainability preference, European institutions have led ESG adoption and provide a useful geographic benchmark.

Table 2 summarizes eMAXX's coverage of institutional holdings. For each bond–quarter observation, we compute the fraction of total shares outstanding that is reported in eMAXX and held by different categories of investors. The table then reports summary statistics of these coverage ratios across the panel.

Panel A shows the results for all bonds in our sample. On average, eMAXX covers 25.15% of the outstanding amount for a typical bond, and 14.72% is held by PRI institutions. The relatively low coverage ratio of institutional bond holdings reflects the regulatory structure of the fixed-income market, where only registered mutual funds are required to publicly disclose portfolio holdings on a regular basis. Other major institutional investors—including pension funds, sovereign wealth funds, and private credit managers—are not subject to mandatory position-level disclosure, even though many of them are PRI signatories. Consequently, both the observable and unobservable portions of the market include a comparable mix of PRI and non-PRI institutions. We therefore view the eMAXX sample as broadly representative of the overall distribution of sustainable investors, despite its limited coverage [11] .

Therefore, we interpret the covered sample as a representative snapshot. Accordingly, more than half of the disclosed institutional positions are associated with PRI signatories, reflecting the breadth of the PRI definition. We also include more conservative values for various calibrations of

[11] Both the Bloomberg and eMAXX datasets exhibit relatively low total institutional-holding ratios. According to the Bloomberg helpdesk, "when total holdings are substantially below 100%, the uncovered portion reflects that Bloomberg only displays holdings reported through public filings or direct disclosures. Many bonds—particularly those traded over the counter (OTC)—do not require all holders to disclose their positions. The missing portion is therefore likely held by institutions that fall below disclosure thresholds, private banks, or other entities that do not report holdings publicly. Retail ownership in the bond market is typically negligible, so the gap arises primarily from limited public reporting rather than retail activity."

the share of sustainable investors, which yields a robust sustainability risk premium.

Panels B and C report the same statistics for SLBs and matched non-SLBs. Overall coverage is lower for both groups. SLBs have 13.42% of their outstanding amounts covered in eMAXX, compared with 9.72% for matched non-SLBs. Despite this limited coverage, the composition within the covered sample is informative: a larger share of disclosed SLB holdings comes from sustainable investors. Using PRI signatories as the baseline definition, 60.22% of covered SLB positions (8.079/13.416) are held by PRI institutions, compared with 51.99% (5.051/9.715) for matched non-SLBs. A similar pattern arises when using the narrower PRI classification or Europe-domiciled investors. Taken together, these patterns indicate that—even within the limited data coverage—SLBs attract a distinctly more sustainable investor base than comparable conventional bonds.

Table 3 summarizes the characteristics of funds that hold SLBs and compares them with the full fund universe across three investor classifications: PRI signatories, narrow PRI signatories, and Europe-domiciled investors.The sample contains 36,274 funds in total since 2019, of which about 12% hold at least one SLB.

Panel A reports the number of funds in each investor group and the fraction that are SLB holders. Across all three classifications, a consistent pattern emerges: sustainable investors are more likely to hold SLBs than their conventional counterparts. Among PRI signatories, 19.2% are SLB holders compared with 0.82% for non-PRI funds. Under the narrow PRI definition, 20.3% of narrow-PRI funds hold SLBs versus 11.7% among non-narrow PRI funds. The contrast is even stronger when comparing Europe-domiciled funds with others: 48.6% of EU-domiciled funds hold SLBs, compared with only 11.0% of non-EU funds.

Panel B compares the average and median AUM under the eMAXX definition[12] of SLB-holding funds with the full fund universe, again using the three classifications of sustainable investors. For the full sample, an SLB holder is substantially larger than the typical fund: the average AUM of SLB holders is 3.59 times that of the average fund. This confirms that SLB ownership is concentrated among larger institutions.

The size differences, however, vary systematically across sustainable and conventional investor groups. Within each sustainability classification, SLB holders that are identified as sustainable

[12]The eMAXX data focus on bond holdings and therefore measure AUM as the total value of bonds held by institutions in the dataset. This measure is a useful proxy for overall AUM when institutions are broadly similar in the share of bonds in their total portfolios.

investors tend to be smaller, on average, than SLB holders that are conventional investors. For example, among PRI signatories, the average SLB-holding fund has 2.25 times the AUM of the average PRI fund, whereas among non-PRI funds the ratio is 4.75. A similar gap appears under the narrow PRI definition (2.44 for narrow PRI vs. 4.06 for non-narrow PRI) and across Europe-domiciled versus non-EU funds (1.20 vs. 4.06). Especially, the average fund AUM for Europe-domiciled funds is 0.86 billion USD for both PRI signatories and the others. However Europe-domiciled SLB holders are much smaller than non Europe-domiciled SLB holders.

A similar pattern appears when using median AUM. SLB holders are still larger than the typical fund, but conditional on sustainability status, sustainable SLB holders remain smaller than their conventional counterparts. The median differences are more pronounced than the mean differences, reflecting the strong right-skewness of fund sizes: a small number of very large institutions raise the average far above the median.

Overall, these results show that SLBs are more actively held by sustainable investors across all three definitions of sustainable investors. At the same time, conditional on being SLB holders, sustainable investors tend to be smaller than their conventional counterparts.

Table 4 examines how much of a fund's AUM is allocated to SLBs relative to its matched non-SLBs. Overall investment in either security is extremely small, reflecting the limited size of the SLB market compared with the broader fixed-income universe and consistent with our treatment of SLBs as a derivative-like instrument for insuring against sustainability performance downturns. Panel A reports results for all funds and shows that SLB holders allocate, on average, 0.562% of AUM to SLBs, slightly more than the 0.503% allocated to matched non-SLBs. Panels B–D repeat the analysis using the three classifications of sustainable investors. Across all definitions—PRI signatories, narrow PRI signatories, and Europe-domiciled funds—sustainable investors allocate a noticeably larger share of AUM to SLBs than to NSLBs. The SLB/NSLB ratios of 1.341 (PRI), 1.778 (narrow PRI), and 1.871 (EU) further indicate that, within each investor group, sustainable investors tilt more strongly toward SLBs relative to otherwise similar bonds.

In summary, this section shows that SLBs closely match the sustainability-contingent hedge claim in our theory along the two conditions required for identification. First, SLBs embed a put-option–a coupon step-up component that pays in bad sustainability states, and its present value is small relative to the overall bond value, making the sustainability-linked leg effectively derivative-like ($\omega_2 \approx 0$ in equation (9)). Second, using eMAXX holdings and multiple definitions of sustainable investors (PRI, narrow PRI, and Europe domicile), we document that SLBs attract a distinct investor clientele: sustainable investors are more likely to hold SLBs and allocate a larger share of their portfolios to SLBs than to otherwise comparable bonds. Despite limited disclosure coverage and the broad nature of PRI-based classifications, the patterns consistently point to stronger segmentation and a higher concentration of sustainable capital in SLBs ($\theta_{s,2} \gg 0$ in equation (13)) than in the broader bond market, aligning with the mechanism through which the market price of sustainability risk becomes observable in our framework.

4 Empirical Results

4.1 Data

Our bond data comes from Bloomberg and include SLB labels, daily trading records, issuance characteristics, and annual sustainability performance. The final sample consists of 771 SLBs and 8,941 non-SLBs issued by SLB-eligible firms between September 2019 and 2023, with trading information extended to August 2025[13]. Sustainability-linked features are manually verified and, when necessary, supplemented using bond prospectuses, company websites, and publicly available sources (e.g., Google Search). Quarterly institutional bond holdings are sourced from the eMAXX database.

4.2 Matched Bonds as Controls

Recall that the SLB price contains two components—a conventional corporate bond and a sustainability-linked put option—such that

$$SLB_t = BD_t + P_t.$$

We assume that the embedded put option does not materially affect the issuer's default risk and focus on using it to reveal investors' sustainability preference and to estimate λ.

Our estimation of λ relies on the factor representation of the put option return in equation (23) and its discrete-time analog in equation (13). In the data, however, we observe only SLB market

[13]We exclude SLBs issued after 2023 because lagged sustainability performance is required.

prices. Because the regular bond component B_t is unobservable, direct calculation of the put option return is infeasible. We therefore adopt an empirically tractable approach that extracts the sustainability risk premium from observed SLB returns by controlling for benchmark bond returns and other bond characteristics. Specifically, the SLB return can be approximated as a weighted average of the returns on the put option and the regular bond:

$$dR(SLB) \approx w \frac{dP_t}{P_t} + (1 - w) \frac{dBD_t}{BD_t}. \tag{32}$$

The benchmark bond must closely resemble the unobserved BD_t in terms of key characteristics (e.g., coupon rate, credit rating, and maturity) to isolate the sustainability-linked component of the SLB.

We match each SLB with a comparable conventional bonds from the same issuer as described in section 3. With a matched non-SLB, we can control for conventional risk-premium channels in SLB returns—such as default and duration risks—and isolate the sustainability-linked component that captures the sustainability risk premium. Combining the put option return in equation (22) with the decomposition of SLB returns in equation (32) gives our main specification for estimating λ:

$$dR(SLB) = \text{constant} + (1 - w)\frac{dBD_t}{BD_t} + w\,\beta_t(\lambda)\big(\lambda\, dt + \tilde{\sigma}_x\, dB_t^x\big).$$

The discrete-time return can be expressed as

$$R_{i,t+1}^{SLB} = \text{constant} + (1 - w)R_{i,t+1}^{NSLB} + w\,\beta_{i,t}(\lambda(i))\big(\lambda(i) + g_{i,t+1}\big), \tag{33}$$

where $\beta_{i,t}(\lambda(i))$ captures the lagged conditional exposure to sustainability risk, and $g_{i,t+1}$ denotes the innovation in the issuer's sustainability performance—the discrete-time analog of $\tilde{\sigma}_x\, dB_t^x(i)$.

4.3 Estimating the Market Price of Sustainability Risk

Based on equation (33) and observed SLB returns, one could in principle estimate a firm-specific sustainability risk premium by choosing $\lambda(i)$ to minimize the fitting error of SLB returns via a non-linear least squares estimator. In practice, however, the SLB market is relatively young and firm-level sustainability metrics are typically disclosed only annually. The resulting time-series for any individual sustainability-contingent claim is therefore short, making bond-by-bond estimation of $\lambda(i)$ imprecise. We instead pool information across the cross section of SLBs and estimate a common, aggregate market price of sustainability risk, λ, from the panel of secondary-market returns.

Our main estimation is constructed at the monthly frequency and specified as

$$R_{i,t+1}^{SLB} = L_i + D_{yr} + w\,\beta_{i,t}(\lambda)\big(\lambda + g_{i,t+1}\big) + (1-w)R_{i,t+1}^{NSLB} + \mathbf{B}^{\top}\mathbf{X} + e_{i,t+1}, \tag{34}$$

where $R_{i,t+1}^{SLB}$ is the holding-period return of SLB i and $R_{i,t+1}^{NSLB}$ is the return of its matched non-SLB benchmark. The fixed effects L_i and D_{yr} absorb persistent bond-level differences and common time variation (e.g., interest-rate and exchange-rate dynamics), as well as any stable label-related pricing patterns (Flammer, 2021; Fama and French, 2007). The matched non-SLB return controls for conventional bond risk channels—including default and term-structure risks—so that the remaining variation in $R_{i,t+1}^{SLB}$ is primarily attributable to the sustainability-linked option component.

The vector $\mathbf{B}^{\top}\mathbf{X}$ includes additional bond-level controls to mitigate omitted-variable bias, including liquidity measures (bid–ask spread and the gamma illiquidity metric of Bao et al. (2011)), issuer default probability from Bloomberg, and time to maturity. We compute holding-period returns following Huynh and Xia (2021) and Lin et al. (2011), incorporating accrued interest and realized coupon payments, and winsorize both return series at the 1% and 99% levels.

Estimating a single λ requires that the cross-sectional aggregation of firm-level sustainability premia can be well represented by a common systematic component. We formalize this by showing that

$$\sum_{i=1}^{I}\beta_{i,t}(\lambda(i))\,\lambda(i) \;\approx\; \sum_{i=1}^{I}\beta_{i,t}(\lambda)\,\lambda, \qquad \text{when} \qquad \lambda = \frac{1}{I}\sum_{i=1}^{I}\lambda(i), \tag{35}$$

where I is the number of SLBs (equivalently, sustainability-contingent claims) in the estimation sample. In Appendix B, we show that this approximation holds under reasonable conditions—in particular, limited dispersion in KPI feasibility and maturities. The approximation implies that the panel of sustainability-contingent returns can be effectively priced by a single systematic price of risk, which justifies estimating λ by fitting the model jointly across all SLBs and substantially improves statistical power relative to bond-by-bond estimation.

Having introduced the common-λ estimation, we now clarify what this parameter represents. Minimizing the total fitting error across SLBs with a single λ corresponds to estimating the cross-sectional average of firm-level premia,

$$\lambda = \frac{1}{I}\sum_{i=1}^{I}\lambda(i).$$

Mapping to the definition of $\lambda(i)$ in equation (27), this common λ can be written as

$$\lambda = -\mathrm{Cov}\left(\frac{1}{I}\sum_{i=1}^{I}\frac{dx_t(i)}{x_t(i)}, \frac{d\pi_t}{\pi_t}\right),$$

which is the market price of sustainability risk for an *equal-weighted portfolio* of firm-level sustainability growth. As with equal-weighted portfolios in other settings, cross-sectional averaging diversifies idiosyncratic components in firm-level sustainability dynamics and isolates the systematic component priced by the economy-wide stochastic discount factor. This interpretation aligns with our benchmark model, where

$$\lambda = \theta_{s,2}\, 2\tilde{\eta}\,\tilde{\sigma}_x^2 + \tilde{\gamma}\,\rho\,\tilde{\sigma}_v\,\tilde{\sigma}_x.$$

Estimating λ requires firm-level sustainability data to construct (i) the innovation term $g_{i,t+1}$ and (ii) the state-dependent exposure $\beta_{i,t}(\lambda)$, as functions of λ implied by equations (29) and (30). Because firm-level sustainability histories are short, we exploit the large cross section of SLBs by pooling observations within KPI categories to estimate the key sustainability-dynamics parameters entering $\beta_{i,t}(\lambda)$ and $g_{i,t+1}$. We proceed in three steps.

Step 1: Unify sustainability indicators. As shown in Figure 2, KPIs include both "good-type" (e.g., renewable energy use) and "bad-type" (e.g., emissions) measures. To align them, we take reciprocals of bad-type indicators—such as carbon emissions, greenhouse gas emissions, and fossil fuel energy consumption—so that higher values consistently reflect better sustainability. In the geometric Brownian motion framework, this transformation reverses the drift but preserves the innovation. We then compute the innovation as

$$g_{i,t+1} = x_{t+1}^i / x_t^i - 1 - \tilde{\mu}_x(i).$$

Step 2: Compute the conditional exposure. Using each SLB's characteristics, we calculate the "moneyness" of the embedded put option,

$$e_t(i) = \frac{\ln(x_t(i)/K(i)) + (\tilde{\mu}_x(i) - \lambda)(T(i) - t) - 0.5\tilde{\sigma}_x(i)^2(T(i) - t)}{\tilde{\sigma}_x(i)\sqrt{T(i) - t}},$$

and obtain $\beta_{i,t}(\lambda)$ accordingly. To improve precision, we classify KPIs into seven categories—raw carbon emissions, carbon emission intensity, raw greenhouse gas emissions, greenhouse gas emission intensity, fossil fuel energy use, renewable energy, and ESG scores—and estimate $\tilde{\mu}_x(i)$ and $\tilde{\sigma}_x(i)$ by averaging within each group.

Step 3: Define targets and horizons. When KPI commitments are expressed as percentage changes, we set $K(i)$ equal to the initial sustainability level times the committed percentage change, converting bad-type targets to their reciprocals. $T(i)$ denotes the evaluation date, and $T(i) - t$ is the time to evaluation.[14]

Table 5 Panel A reports summary statistics for the cross-sectional distribution of time-series moment estimates for each issuer's underlying sustainability growth process—$\tilde{\mu}_x$, $\tilde{\sigma}_x$, the correlation ρ between sustainability growth and SLB holding returns, and the conditional factor exposure β defined in equation (23). Specifically, for each issuer–KPI pair we first compute the time-series estimates of $\tilde{\mu}_x$ and $\tilde{\sigma}_x$, and then summarize their cross-sectional distribution (mean, median, etc.). This procedure provides smoothed estimates that mitigate short time-series noise and yields an aggregate assessment of sustainability risk. We take the cross-sectional means as proxies for the model parameters, implying an average expected growth rate $\tilde{\mu}_x = 0.092$ and an average volatility $\tilde{\sigma}_x = 0.221$ at the annual frequency. Likewise, we find a weak unconditional correlation between sustainability outcomes and SLB returns, $\rho = -0.031$ (p-value = 0.63).

We estimate λ using the two-step nonlinear least squares procedure described above. Our main specification, summarized in Panel B of Table 5, is based on *monthly* SLB returns. Because the sustainability performance features that underlie the embedded put option are updated only once a year, we assume they remain constant within each year. This assumption enables us to exploit monthly return variation in both SLBs and their benchmark non-SLB counterparts, substantially

[14] If multiple evaluation dates exist, we use the first one since the market tends to respond most significantly to the first event (Flammer (2021), Kölbel and Lambillon (2022)). For multiple KPIs on the same date, we retain the type with the largest coupon step-up, which accounts for 71% of total step-up amounts and captures the strongest market response.

expanding the time-series dimension and improving numerical stability. The estimated sustainability risk premium is $\lambda = 0.076$ ($t = 6.96$), statistically and economically significant.

To verify that this result is not driven by sample composition, we re-estimate λ across key market segments. The largest region (Europe) and the dominant issuing sector (Industrial) deliver nearly identical estimates ($\lambda = 0.08$, $\lambda = 0.078$, $t = 7.18$ and $t = 7.11$, respectively), confirming the stability of the premium across geography and industry. We further consider two KPI-based subsamples. The first uses ESG scores, which are known to be more sensitive to measurement and disclosure manipulation; its lower estimate ($\lambda = 0.048$, $t = 10.35$) aligns with the literature suggesting weaker information content in ESG-based indicators. The second focuses on raw-emission KPIs, measuring absolute GHG or CO_2 levels.[15] This group yields a higher but less precise estimate ($\lambda = 0.115$, $t = 2.59$), reflecting both its stronger link to physical sustainability outcomes, as well as dependency on sales and revenues. Finally, to ensure our results are not affected by contractual complexity, we exclude callable SLBs and re-estimate the premium on the non-callable subsample, obtaining a similar result ($\lambda = 0.067$, $t = 4.18$). Together, these exercises demonstrate that the estimated λ is robust across market segments, KPI types, and instrument structures.

The regression framework further allows a decomposition of SLB return variation into four components: benchmark non-SLB returns, the put-option factor, other controls, and fixed effects.[16] In the first decomposition—relative to total variance—benchmark non-SLB returns explain the majority (56.1%), as expected, while the put-option factor accounts for only 0.06% because the embedded option represents a very small share of the bond's total value. Without the structural option-pricing framework, such a small component could easily be understated or overstated, leading to biased inference about the sustainability risk premium. Our model explicitly accounts for this structure, allowing precise identification of λ even when the option leg is quantitatively minor.

In the second decomposition—conditioning on the residual variance excluding the benchmark bond return component—the relative importance of the put-option term rises substantially. Within the remaining variation, the put option explains about 4.6%, and the fixed effects dominate with roughly 91.0%. The fixed-effect term captures persistent behavioral or label-related pricing patterns—investors' willingness to pay a premium for sustainability-labeled securities—consistent with

[15] An alternative emission measure, emission intensity, scales absolute emissions by firm fundamentals such as sales.

[16] We use a Frisch–Waugh–Lovell–style decomposition: for each component of the explanatory variables, the remaining regressors are partialed out to isolate its marginal explanatory power for SLB returns.

the presence of non-pecuniary preferences. Across subsamples, these decomposition patterns are broadly similar. There is a notable deviation in the ESG-score group, where benchmark non-SLB returns explain a smaller share (44.1%) and both the fixed effects and put-option components play relatively larger roles. This pattern suggests that investors may perceive greater uncertainty or potential manipulation in ESG-based KPIs and therefore place greater weight on hedging and label-related channels when pricing these SLBs.

Panel C presents a complementary *yearly* estimation in which both sustainability features and returns are measured at the same frequency. Since the data are observed at the SLB–year level, we refine the fixed-effect structure to include industry, country, and year effects, ensuring that cross-sectional and temporal heterogeneity is properly absorbed. This specification is more conservative, as it removes the assumption of within-year constancy but reduces the number of observations, making some subsample estimations numerically unstable. The estimated premium, $\lambda = 0.072$ ($t = 2.57$), remains highly consistent with the monthly result, confirming robustness. As expected, the explanatory power of benchmark non-SLB returns declines sharply (to 11.8%) due to lower time-series variation, while the contribution of fixed effects becomes more pronounced. The magnitude of the put-option component, however, remains comparable, underscoring the stability of the identified sustainability risk premium. Overall, the decomposition patterns in the yearly data mirror those from the monthly specification, reinforcing the reliability and structural interpretability of our framework.

As a validation of our approach, Table 6 reports the linear regression estimates from equation (34), where $\beta_{i,t}(\lambda)$ is constructed using the full-sample monthly estimate $\lambda = 0.076$. Column (1) presents our baseline specification, which controls for liquidity, issuer default probability, maturity, and matched-bond characteristics through the vector $\mathbf{B}^\top \mathbf{X}$, together with SLB and year fixed effects. The two key coefficients—the benchmark non-SLB return and the put-option component $\beta_{i,t}(\lambda)\big(\lambda + g_{i,t}\big)$—are both positive and significant, consistent with the model-implied decomposition of SLB returns.

Columns (2)–(3) examine alternative fixed-effect structures by replacing SLB and year fixed effects with SLB–year effects in Column (2) and with SLB-only effects in Column (3). Across these specifications, the coefficients on both the benchmark return and the put-option component remain virtually unchanged, demonstrating that our main results are not sensitive to the way SLB-level heterogeneity is absorbed. Columns (4)–(6) further expand the fixed-effect structure to include firm–year effects (Column 4), country and industry effects (Column 5), and the most saturated design with country–year and industry–year fixed effects (Column 6). In these specifications, to better isolate bond-specific variation, we additionally control for the matching gaps between each SLB and its paired non-SLB in issuance amount, coupon rate, issuance date, and maturity at issuance. The estimated coefficient on the put-option term remains statistically significant and has a similar magnitude across all three columns.

Taken together, these regression results confirm that the structural return decomposition implied by our model is robust across a wide range of fixed-effect and control-variable specifications, and that the put-option component—despite its small economic weight—is precisely recovered in the data.

4.4 Reconcile with Mixed Findings in Traditional Assets Testing Sustainability Risk Premium

Following the factor representation in Proposition 2, the market price of sustainability risk λ decomposes into two components,

$$\lambda = \lambda_x + \lambda_v, \qquad \lambda_x = \theta_{s,2}\, 2\tilde{\eta}\tilde{\sigma}_x^2, \qquad \lambda_v = \tilde{\gamma}\rho\,\tilde{\sigma}_v\tilde{\sigma}_x.$$

The same two channels also enter the expected return of the market-index asset:

$$\tilde{\mu}_1 - r_f = \underbrace{-\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\tilde{\mu}_x}_{\text{non-pecuniary preference reward}} + \underbrace{\frac{1}{2}\frac{\theta_{s,1}}{\theta_{s,2}}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_x}_{\text{sustainability risk premium}} + \underbrace{2\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_v + \tilde{\gamma}\tilde{\sigma}_v^2}_{\text{traditional risk premium}}.$$

Our estimate of λ from sustainability-contingent claims provides a convenient way to translate the pricing of the hedge component into implications for traditional assets. The same representation also clarifies why tests of SRP using stocks or conventional bonds tend to produce mixed evidence. Two forces work against detection in traditional assets. First, sustainability enters expected returns through two terms with opposite signs (a reward channel versus a risk channel), so their net effect can be small even when each component is economically meaningful. Second, both channels are scaled by the sustainable-capital share in the broad market, $\theta_{s,1}$, which is empirically small; this dilution further shrinks the sustainability-related expected-return component in traditional assets relative to sustainability-contingent claims, where sustainable participation is more concentrated ($\theta_{s,2}$ is larger).

To make this point concrete, we take equities as a leading example and discipline the benchmark model using standard moments. We set the equity premium to $\mu_1 - r_f = 0.08$ with volatility $\sigma_v = 0.15$, and use our empirical estimate $\lambda = 0.076$. Based on the summary statistics in Table 5 and the discussion in the previous section, we set $\tilde{\mu}_x = 0.092$, $\tilde{\sigma}_x = 0.221$, and start with $\rho = 0$ for simplicity. Given these targets, we back out the preference parameters $(\tilde{\gamma}, \tilde{\eta})$ implied by the joint pricing restrictions. These implied parameters allow us to quantify the magnitude of each term in expected returns—reward, sustainability risk, and traditional risk—and therefore make our explanation transparent as to why the net SRP effect is small in traditional assets. Appendix A provides the detailed steps.

A central input is the pair $(\theta_{s,1}, \theta_{s,2})$, which captures sustainable participation in the traditional market and in the sustainability-contingent segment. Table 7 reports these shares under several definitions. An AUM-based PRI measure yields an implausibly high $\theta_{s,1}$, which we view as reflecting limited eMAXX coverage, strong size skewness among institutions, and the broad nature of PRI signatory status. We therefore adopt a more robust participation-based measure using the *number* of funds, which aligns with survey-based approaches that measure segmentation through participation rather than wealth aggregates (Riedl and Smeets, 2017; Bauer et al., 2021; Humphrey et al., 2021; Giglio et al., 2025; Krueger et al., 2020). We consider three count-based scenarios: broad PRI, narrow PRI, and a stringent intersection definition (PRI $\cap$ active SLB holders). For completeness, we also report the AUM-based PRI scenario as an upper bound.

Across these scenarios, $\theta_{s,2}$ is consistently higher than $\theta_{s,1}$, implying stronger concentration of sustainable participation in the sustainability-contingent segment. In the benchmark (intersection) scenario $(\theta_{s,1}, \theta_{s,2}) = (0.05, 0.40)$, $\rho = 0$ implies $\lambda_x = \lambda = 7.60\%$. Plugging into (14), the sustainability-related components of the equity premium are -0.25% (reward) and $+0.26\%$ (risk), yielding a negligible net effect of about 0.01%. In the same scenario, the implied sustainability premium on the contingent leg is sizable at the option level ($\beta\lambda_x$), but translates into a modest effect on the overall SLB return because the option component is small ($w\beta\lambda_x \approx -0.55\%$ with $w \simeq 0.02$). Allowing for $\rho = \pm 0.3$ shifts the decomposition between λ_x and λ_v, but the equity implication remains similar: the non-pecuniary preference reward and risk terms continue to offset, and their net contribution remains small across segmentation scenarios.

Overall, this exercise reconciles our finding of a meaningful market price of sustainability risk in sustainability-contingent claims with the mixed evidence from traditional-asset tests. The same underlying pricing forces that generate a sizable λ in the segmented, hedge-claim market imply a small and hard-to-detect sustainability component in equities and conventional bonds due to dilution (small $\theta_{s,1}$) and near-cancellation between reward and risk channels.

5 Conclusion

This paper studies how investors' non-pecuniary sustainability preferences are reflected in asset prices by focusing on securities that provide an explicit hedge against sustainability underperformance. Our theoretical framework introduces a sustainability-contingent claim whose financial payoff is negatively linked to sustainability performance. In equilibrium, this contingent claim is priced primarily for its hedging role, yielding a clean mapping between its expected return and the market price of sustainability risk. This insight highlights why sustainability-contingent hedging claims provide a more direct testing instrument for the sustainability risk premium than traditional assets, where sustainability-related expected returns are both diluted by the small share of sustainable capital and subject to offsetting non-pecuniary preference reward and sustainability risk premium.

We take sustainability-linked bonds (SLBs) as an empirical proxy for this sustainability-contingent claim. SLBs embed a coupon step-up that is economically a put option on sustainability performance. This put option fits the stylized condition in our theory that it has negligible market size and a more concentrated group of sustainable investors than traditional assets. We develop an estimation framework to use matched non-SLB benchmarks as control and separate the sustainability-linked component to recover a market price of sustainability risk λ. The empirical results indicate a sizable sustainability risk premium in the sustainability-contingent claim, consistent with economically meaningful hedging demand in a market with concentrated participation by sustainable investors.

Mapping the estimated λ back into the benchmark pricing framework also clarifies why sustainability risk premium is difficult to detect in traditional assets such as equities and conventional bonds. Under the same underlying preferences and market-clearing forces, sustainability enters expected returns through channels that tend to offset and that are scaled by the small sustainable-capital share in the broad market. In contrast, the expected returns in sustainability contingent claims only consist of the sustainability risk premium without the sustainability preference reward. As a result, sustainability-related excess return can be economically meaningful in contingent hedging claims while appearing small in traditional assets, helping reconcile the mixed findings in the existing literature.

More broadly, our analysis highlights that SLBs are not just another labeled fixed-income product, but a useful 'measurement asset" for sustainability. Because they combine an explicit sustainability-linked payoff with a concentrated base of sustainable investors, they allow us to separately identify the reward and risk components of sustainability-related returns and to quantify the strength of sustainability preferences in a way that is extremely hard to achieve using traditional assets alone. In this sense, SLBs play a role for sustainability preferences that is analogous to the role of index options for financial risk premia.

The paper also opens several avenues for future research. On the theory side, it would be natural to extend our framework to richer forms of dynamics, e.g., allowing an endogenous fraction of sustainable investors. From a different angle, one can ask why and when a firm should issue SLBs and how to design their KPIs. On the empirical side, longer time series and more granular sustainability data would permit finer identification of how sustainability risk premium responds to policy changes, regulatory regimes, or real improvements in environmental and social outcomes. We view our results as a first step towards a systematic asset-pricing analysis of sustainability risks.

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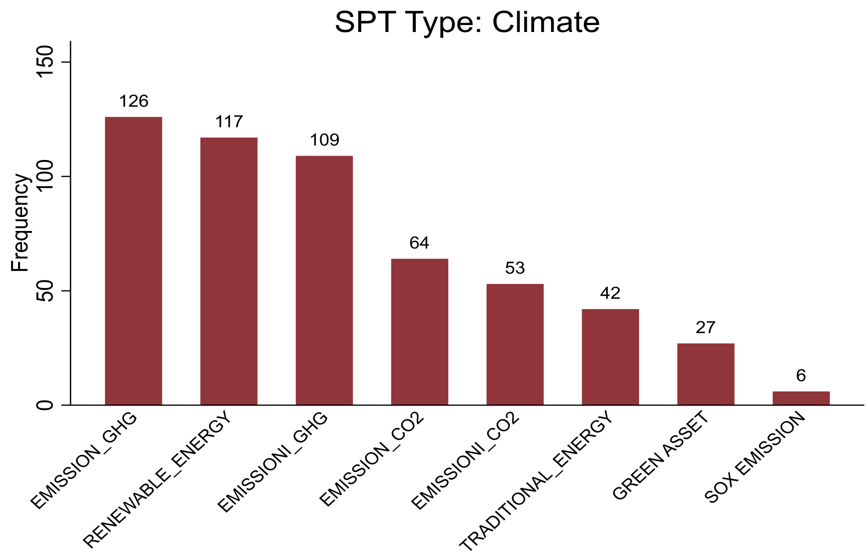
Issuer Information
Name ENEL FINANCE INTL NV
Industry Electric (BCLASS)
Security Information
Mkt Iss EURO MTN
Ctry/Reg NL Currency EUR
Rank Sr Unsecured Series EMTN
Coupon 0 Type Fixed
Cpn Freq Annual
Day Cnt ACT/ACT Iss Price 98.90900
Maturity 06/17/2027 Reoffer 98.909
MAKE WHOLE @15.000 until 03/17/27/ CALL 03/...
Iss Sprd +38.00bp vs Mid Swaps
Calc Type (1)STREET CONVENTION
Pricing Date 06/08/2021
Interest Accrual Date 06/17/2021
1st Settle Date 06/17/2021
1st Coupon Date 06/17/2022

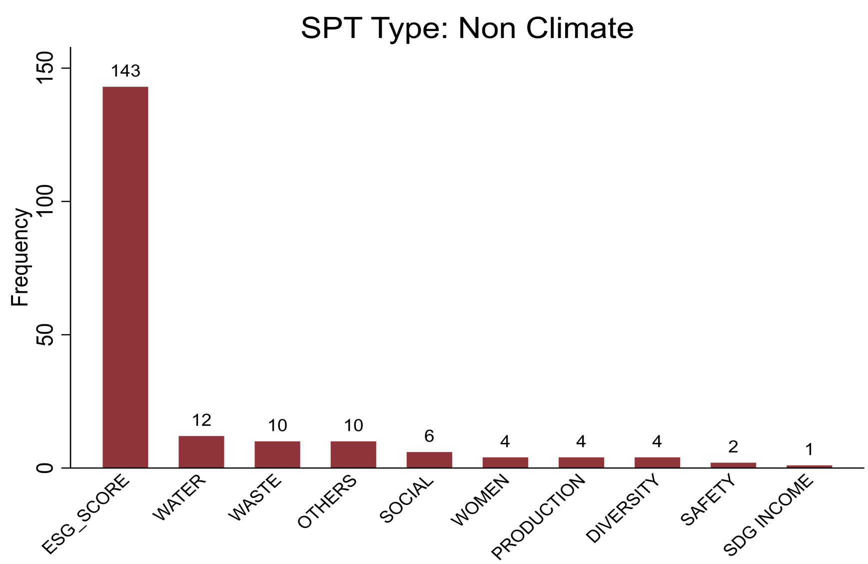
Identifiers
FIGI BBG011C64FX5
ISIN XS2353182020
ID Number BP9829774
Bond Ratings
Moody's Baa1
S&P BBB+
Fitch BBB+
Composite BBB+
Issuance & Trading
Amt Issued/Outstanding
EUR 1,000,000.00 (M) /
EUR 1,000,000.00 (M)
Min Piece/Increment
100,000.00/ 1,000.00
Par Amount 1,000.00
Book Runner JOINT LEADS
Exchange EURONEXT-DUBLIN

STEP-UP MARGIN: 25BP, STEP-UP EVENT: 12/31/2023 GREENHOUSE GAS EMISSIONS ABOVE 148G/KWHEQ

Figure 1: SLB Example
This figure provides the information of the SLB issued by ENEL FINANCE INTEL NV. This is a screenshot on the bond information from Bloomberg Terminal.



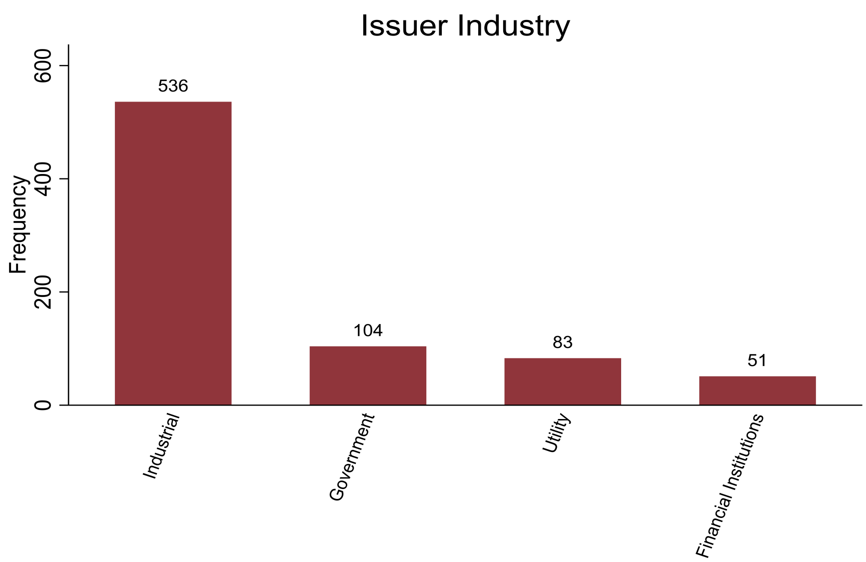
(A)



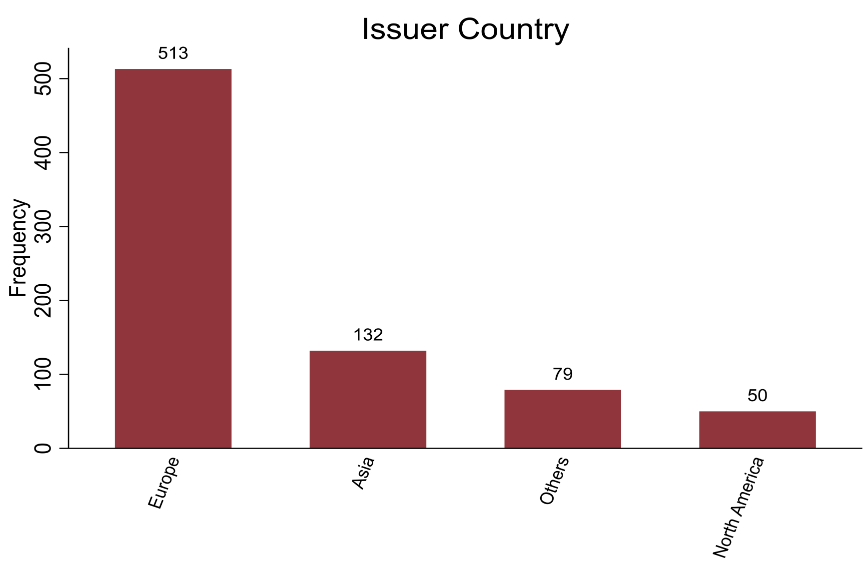
(B)

FIGURE 2: Sustainability Performance KPI Type

This figure plots the distribution of the type of sustainability performance KPI. X-axis is the type of sustainability performance KPI. Y-axis is the number of SLBs with the corresponding KPI type. Information is obtained from Bloomberg in 27 November 2023 and manually complemented by prospectus, firm website, media and google.

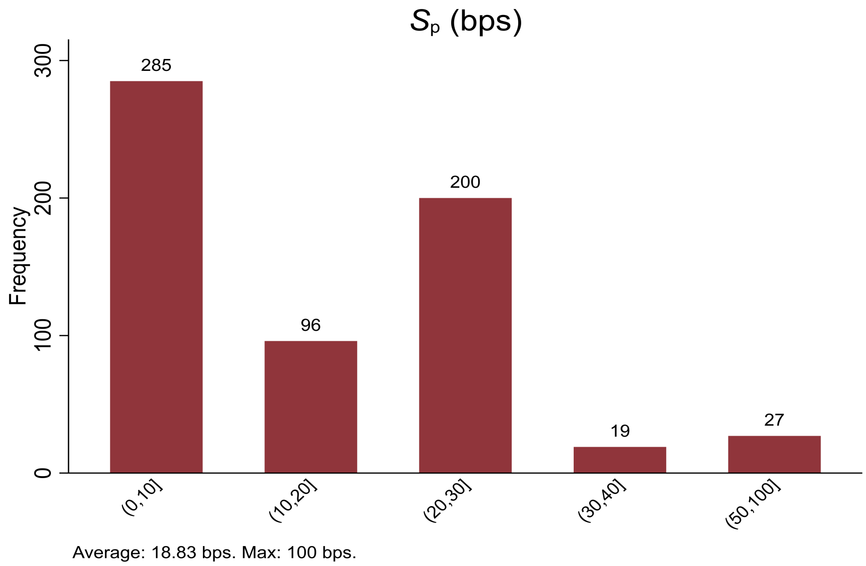


(A)

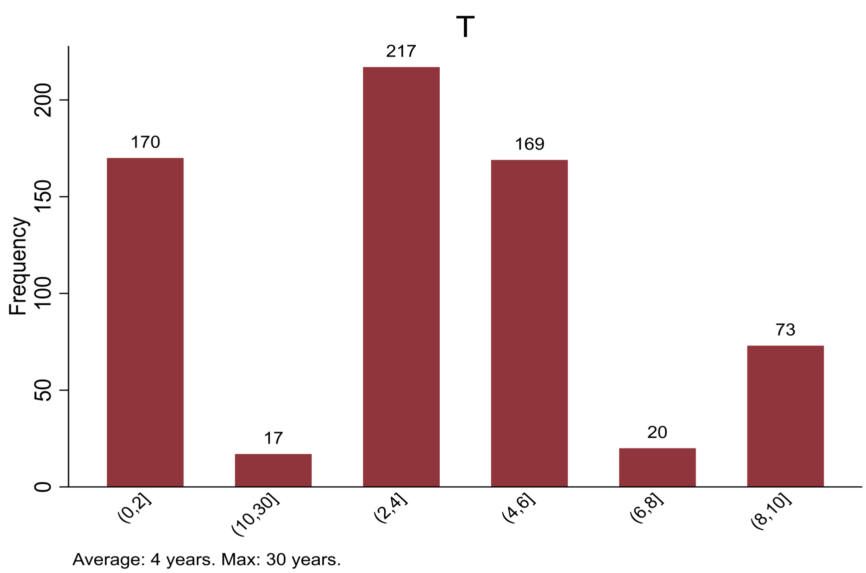


(B)

FIGURE 3: Distributions of Issuer Industry and Area
This figure plots the distributions of the industry and country for the issuer. Information is obtained from Bloomberg in 27 November 2023 and manually complemented by prospectus, firm website, media and google.



(A)



(B)

FIGURE 4: Distributions of Coupon Step-up S_p and Years to the Evaluation Date at Issuance T
This figure plots the distributions coupon step-up S_p and years to the evaluation date at Issuance T . Information is obtained from Bloomberg in 27 November 2023 and manually complemented by prospectus, firm website, media and google.

Table 1: Summary Stats: All SLBs and Non-SLBs from SLB Issuers

This table reports the summary statistics of all 771 SLBs and 9020 non-SLBs from SLB issuers on the issuing information. *Yldsprd_ISS* is the yield spreads at issuance, in bps, related to the interpolated risk-free yield based on the Treasury. *Price_ISS* is the issuing price. *Coupon* is the coupon rate at issuance. *Maturity* is the maturity of bond in year at issuance. Amt_ISS (M$) is the issuing amount in million dollars. *RATING_ISS* is the Standard Poor Rating of Issuance, 1 for D, 2 for C, 3 for CC,..., 22 for AAA. Panel A displays the values for paired SLBs. Panel B displays the value for all Non-SLBs issued by SLB issuers. Data is from Bloomberg.

Variable	Obs	Min	Mean	Median	Max	SD	diff	T	P-Value
Panel A: All SLBs									
Yldsprd_ISS	262	6.5	239.6	185	748	169.7			
Price_ISS	501	94	99.7	100	107.8	0.769			
Coupon	771	0	2.713	2.48	13.48	2.802			
Maturity_Year	757	1.5	7.232	7.003	60.04	4.604			
Amt_ISS (M$)	769	9.3	440.9	358.13	2200	356			
RATING_ISS	282	3 CC	12.31 BB+	13 BBB-	20 AA	3.123			
Panel A: Non-SLBs issued by SLB Issuers							**SLB - NSLB**		
Coupon	8941	-0	2.769	2.5	30	3.003	-0.056	-0.504	0.307
Maturity_Year	8379	0	10.03	6.005	80.06	10.49	-2.788	-7.24	0
Amt_ISS (M$)	8055	0	2200	147.99	98062	8419	-87.360	-3.736	0
RATING_ISS	1635	4 CCC-	15.56 A-	16 A-	22 AAA+	3.32	-3.251	-15.297	0

Table 2: Institutional Holdings Covered by eMAXX

This table reports summary statistics on institutional holdings normalized by total bond outstanding. For each bond–quarter observation, we compute the fraction of outstanding amounts held by four categories of investors based on eMAXX disclosures: (i) all institutions, (ii) PRI signatories, (iii) narrow PRI signatories, and (iv) Europe-domiciled investors. Each measure is defined as the ratio of eMAXX-reported holdings for that investor group to the bond's total shares outstanding in the same quarter. PRI signatories are identified through fuzzy matching and manual verification of institutional names and domiciles. The "Narrow PRI" category restricts the sample to PRI signatories classified as Investment Managers and with trading dates after their PRI sign-up (Gibson Brandon et al., 2022). Summary statistics are reported separately for the full bond sample, for SLBs, and for matched non-SLBs. The sample spans 2019–2024 and is structured as a bond–quarter panel.

Holdings Covered by eMAXX / Total Shares Outstanding (%)					
Category	min	Mean	Median	Max	SD
Panel A: All Bonds					
Held by ALL Institutions	0	25.153	12.5	100	28.559
Held by PRI Institutions	0	14.72	3.781	100	22.625
Held by Narrow PRI Institutions	0	5.304	0	100	14.665
Held by EU Domiciled Institutions	0	0.832	0	100	4.905
Panel B: SLBs					
Held by ALL Institutions	0	13.416	5.46	95.492	17.276
Held by PRI Institutions	0	8.079	3.316	68.98	10.865
Held by Narrow PRI Institutions	0	2.827	0.477	42.473	5.078
Held by EU Domiciled Institutions	0	1.822	0.685	69.059	3.036
Panel C: Matched NSLBs					
Held by ALL Institutions	0	9.715	2.514	94.924	15.695
Held by PRI Institutions	0	5.051	1.401	57.093	8.18
Held by Narrow PRI Institutions	0	1.595	0.077	51.425	3.729
Held by EU Domiciled Institutions	0	1.099	0.283	19.126	1.979

Table 3: Institutional Characteristics of SLB Holders

This table compares SLB-holding funds with the full sample of funds across three investor classifications: (i) PRI signatories vs. non-PRI, (ii) narrow PRI signatories vs. non–narrow PRI, and (iii) Europe-domiciled vs. non-Europe funds. PRI signatories are identified through fuzzy matching and manual verification of institutional names and domiciles. The "narrow PRI" category restricts the sample to PRI signatories classified as Investment Managers and with trading dates after their PRI sign-up (Gibson Brandon et al., 2022). The sample is a fund–quarter panel spanning 2019–2024. *Panel A* reports the number of funds in each group and the number and share that hold SLBs. *Panel B* reports fund size (AUM, in billions of USD), summarizing mean and median AUM for all funds and for SLB holders, along with their ratios.

		PRI vs Not PRI		Narrow PRI vs Not Narrow PRI		EU vs Not EU	
	All Funds	PRI	Not PRI	Narrow PRI	Not Narrow PRI	EU	Not EU
Panel A: Number of Funds — SLB Holders vs. Full Sample							
Total Number	36,274	14,334	22,269	7,900	34,072	1,587	32,507
Number of SLB Holders	4,394	2,751	1,836	1,601	4,000	772	3,578
SLB Holder / Total	0.121	0.192	0.082	0.203	0.117	0.486	0.110
Panel B: AUM B$ (Mean, Median) — SLB Holders vs. Full Sample							
All Fund Average	0.860	1.440	0.489	1.123	0.821	0.861	0.860
SLB Holder Average	3.086	3.234	2.836	2.744	3.195	1.037	3.493
SLB Holder Average / All Fund Average	3.588	2.245	5.806	2.444	3.890	1.204	4.062
All Fund Median	0.013	0.067	0.001	0.090	0.008	0.139	0.011
SLB Holder Median	0.372	0.401	0.317	0.378	0.369	0.232	0.407
SLB Holder Median / All Fund Median	27.794	6.012	421.486	4.180	45.409	1.667	38.410

Table 4: Share of Fund AUM Allocated to SLBs and Matched Non-SLBs

This table reports, for funds that hold SLBs or their matched non-SLBs (NSLBs), the fraction of each fund's total AUM invested in these securities. For each fund–quarter observation, we compute the holding in SLBs (or NSLBs) divided by the fund's total AUM. Results are reported separately for four investor classifications: (i) all funds, (ii) PRI signatories, (iii) narrow PRI signatories, and (iv) Europe-domiciled funds. The SLB/NSLB ratio summarizes the mean SLB allocation relative to the mean NSLB allocation within each panel. PRI signatories are identified through fuzzy matching and manual verification of institutional names and domiciles. The "Narrow PRI" category restricts the sample to PRI signatories classified as Investment Managers and with trading dates after their PRI sign-up (Gibson Brandon et al., 2022). The sample is a fund–quarter panel from 2019–2024.

	min	Mean	Median	Max	SD
Panel A: All Funds					
SLB (% of AUM)	0	0.562	0.109	100	2.788
NSLB (% of AUM)	0	0.503	0.096	68.163	1.629
SLB / NSLB Ratio		1.117	1.135		
Panel B: PRI Signatories					
SLB (% of AUM)	0	0.496	0.133	100	2.067
NSLB (% of AUM)	0	0.37	0.086	68.163	1.188
SLB / NSLB Ratio		1.341	1.547		
Panel C: Narrow PRI Signatories					
SLB (% of AUM)	0	0.583	0.169	100	2.337
NSLB (% of AUM)	0	0.328	0.08	32.553	1.098
SLB / NSLB Ratio		1.777	2.113		
Panel D: Europe-Domiciled Funds					
SLB (% of AUM)	0	0.941	0.372	100	3.341
NSLB (% of AUM)	0	0.503	0.203	54.503	1.08
SLB / NSLB Ratio		1.871	1.833		

TABLE 5: Estimation of λ and Variance Decomposition

This table reports the estimated sustainability risk premium λ in the SLB put-option component, derived from equation (10), along with associated t-statistics and RMSEs from the two-step procedure in Appendix C. Panel A summarizes the cross-sectional average of the time-series moments estimate for each underlying sustainability growth—μ_x, σ_x, the correlation ρ between sustainability growth and SLB holding returns, and the conditional factor exposure β defined in equation (23). Panel B presents the baseline monthly estimation with SLB and year fixed effects. Panel C reports the yearly estimation with industry, country, and year fixed effects. Across panels, columns correspond to the full sample, European issuers, the Industrial sector, SLBs with raw-emission KPIs, SLBs with ESG-score KPIs, and non-callable SLBs. "VarExplained" indicates the fraction of total variance in SLB returns explained by each component—benchmark non-SLB returns (NSLB Ret), the conditional factor term $\beta_{i,t}(\lambda)\big(\lambda + g_{i,t+1}\big)$ associated with the embedded put option, other controls (excluding NSLB Ret, the put option factor, and fixed effects), and fixed effects (FE). The lower rows in each panel report the relative shares of variance within the residual component (i.e., excluding the benchmark NSLB return). The sample period is from September 2019 to August 2025. All values in the variance decomposition are expressed in percentages.

Panel A: Summary Statistics

	N	Min	Mean	Median	Max	SD
μ_x	105	-0.1920	0.0920	0.0490	1.3100	0.1970
σ_x	105	0.0020	0.2210	0.1510	1.2670	0.2140
β	4469	-53.4600	-3.6300	-0.9500	0.0000	8.7050

ρ =Corr(R^{SLB}, dx) =-0.031 , p-val=0.63

Panel B: Monthly Estimation (FEs: SLB, Year)

	All	EU	Industrial	Raw Emission	ESG Score	Non-Callable
λ	0.076	0.080	0.078	0.115	0.048	0.067
t-stat	6.958	7.182	7.110	2.588	10.353	4.178
RMSE	0.209	0.223	0.211	0.176	0.244	0.164
Relative Shares to Total Variance (%)						
NSLB Ret	56.07	55.46	51.80	60.87	44.18	26.33
Put Option	0.06	0.09	0.09	0.02	1.92	0.39
Controls	0.06	0.09	0.06	0.05	0.61	0.24
Fixed Effects	1.22	1.53	1.37	1.25	6.67	2.82
Relative Shares Within Terms Except NSLB (%)						
Put Option (within-rest)	4.57	5.34	5.88	1.81	20.89	11.26
Controls (within-rest)	4.41	5.17	3.75	4.13	6.63	6.96
Fixed Effects (within-rest)	91.02	89.49	90.37	94.07	72.48	81.78

Panel C: Yearly Estimation (FEs: Industry, Country, Year)

	All	EU	Industrial
λ	0.072	0.094	0.071
t-stat	2.566	3.347	4.669
RMSE	0.037	0.041	0.032
Relative Shares to Total Variance (%)			
NSLB Ret	11.82	7.33	5.89
Put Option	0.09	0.09	0.40
Controls	0.69	0.50	0.86
Fixed Effects	7.17	5.48	10.04
Relative Shares Within Terms Except NSLB (%)			
Put Option (within-rest)	1.16	1.45	3.54
Controls (within-rest)	8.69	8.20	7.64
Fixed Effects (within-rest)	90.15	90.36	88.82

Table 6: Panel Regression Results with $\lambda = 0.076$

This table reports estimates of equation (34) using monthly SLB returns and the optimal value $\lambda = 0.076$. Columns (1)–(6) correspond to alternative combinations of fixed effects listed in the lower panel. The dependent variable is the SLB holding return $R_{t+1}^{SLB}(i)$, with the matched non-SLB return $R_{t+1}^{NSLB}(i)$ serving as the benchmark control. The term $\beta_{i,t}(\lambda)(\lambda + g_{i,t})$ captures the sustainability-linked component of SLB returns implied by the option-pricing framework. The controlling variables includes measures of liquidity (bid–ask spread and the gamma illiquidity metric of Bao et al. (2011)), issuer default probability from Bloomberg, and time to maturity, as well as issuance-date, issuance-amount, coupon, and maturity gaps between each SLB and its matched non-SLB. The sample period is from September 2019 to August 2025. t-statistics, based on standard errors clustered by country, are reported in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
	$R_{t+1}^{SLB}(i)$	$R_{t+1}^{SLB}(i)$	$R_{t+1}^{SLB}(i)$	$R_{t+1}^{SLB}(i)$	$R_{t+1}^{SLB}(i)$	$R_{t+1}^{SLB}(i)$
$R_{t+1}^{NSLB}(i)$	1.01***	1.02***	1.02***	1.01***	1.01***	1.01***
	(23.20)	(23.06)	(23.89)	(23.16)	(22.81)	(22.53)
$\beta_{i,t}(\lambda)(\lambda + g_{i,t})$	0.01**	0.02*	0.01**	0.01**	0.01**	0.01*
	(2.15)	(1.94)	(2.07)	(2.18)	(2.32)	(1.94)
Bid-ask Spread	3.57**	6.08**	3.43***	3.07**	2.85**	3.03**
	(2.29)	(2.45)	(2.80)	(2.16)	(2.07)	(2.12)
Gamma	0.02	0.03	0.02	0.02	0.02	0.03
	(0.47)	(0.65)	(0.46)	(0.47)	(0.62)	(0.76)
Default Prob	0.45	0.64	0.30	0.43	0.11	0.02
	(1.21)	(1.18)	(0.77)	(1.19)	(0.64)	(0.09)
Maturity	-0.00	-0.00	-0.00**	-0.00	0.00	0.00
	(-0.46)	(-0.03)	(-2.44)	(-1.01)	(0.32)	(0.17)
ISS_AMT_gap				-0.00	-0.00	0.00
				(-0.36)	(-0.33)	(0.70)
Cpn_gap				0.02*	0.00	0.00
				(1.83)	(0.18)	(0.20)
iss_date_gap				-0.00	0.00	0.00**
				(-0.65)	(1.62)	(2.21)
Maturity_gap				-0.00	-0.00***	-0.00***
				(-1.09)	(-4.00)	(-3.65)
SLB FE	Y		Y			
Year FE	Y			Y	Y	
SLB–Year FE		Y				
Firm FE				Y		
Country FE					Y	
Industry FE					Y	
Country–Year FE						Y
Industry–Year FE						Y
Constant	0.02	-0.03	0.06*	0.01	-0.01	-0.01
	(0.21)	(-0.29)	(1.91)	(0.96)	(-1.70)	(-1.56)
Observations	3,168	3,151	3,168	3,172	3,172	3,170
R-squared	0.64	0.65	0.63	0.64	0.63	0.64

TABLE 7: Quarterly Estimates of Sustainable-Capital Shares $\theta_{s,1}$ and $\theta_{s,2}$

This table reports quarterly estimates of the sustainable-capital shares $\theta_{s,1}$ and $\theta_{s,2}$, defined in equations (**??**) and (**??**). Sustainable investors are classified in three ways: (i) all PRI signatories; (ii) a narrow subset of PRI signatories; and (iii) funds that are both PRI signatories and active SLB holders. PRI signatories are identified via fuzzy-matched and manually verified institutional names and domiciles, and the "Narrow PRI" category follows Gibson Brandon et al. (2022) by retaining only Investment Managers with trading activity after their PRI sign-up. Using these classifications, we construct $\theta_{s,1}$ and $\theta_{s,2}$ based on the *number* of funds. For comparison, the first set of columns reports an AUM-based version of the PRI classification, where $\theta_{s,1}$ and $\theta_{s,2}$ are computed using the share of assets under management held by PRI institutions in each market. The last row reports time-series averages.

	PRI (AUM-based)		**PRI**		**PRI–Narrow**		**PRI & SLB Holder**	
Quarter	$\theta_{s,1}$	$\theta_{s,2}$	$\theta_{s,1}$	$\theta_{s,2}$	$\theta_{s,1}$	$\theta_{s,2}$	$\theta_{s,1}$	$\theta_{s,2}$
2020q3	0.36	0.86	0.04	0.46	0.03	0.35	0.01	0.46
2020q4	0.62	0.93	0.06	0.68	0.04	0.45	0.02	0.68
2021q1	0.20	0.41	0.04	0.19	0.02	0.10	0.01	0.19
2021q2	0.29	0.48	0.07	0.39	0.03	0.22	0.03	0.39
2021q3	0.33	0.47	0.10	0.43	0.06	0.25	0.06	0.43
2021q4	0.58	0.73	0.11	0.58	0.06	0.33	0.07	0.58
2022q1	0.16	0.25	0.04	0.18	0.01	0.06	0.03	0.18
2022q2	0.23	0.36	0.06	0.31	0.03	0.16	0.04	0.31
2022q3	0.37	0.51	0.10	0.46	0.06	0.28	0.07	0.46
2022q4	0.67	0.80	0.12	0.63	0.07	0.37	0.08	0.63
2023q1	0.20	0.30	0.04	0.19	0.02	0.09	0.03	0.19
2023q2	0.28	0.39	0.08	0.34	0.05	0.20	0.05	0.34
2023q3	0.36	0.48	0.13	0.47	0.09	0.31	0.09	0.47
2023q4	0.69	0.80	0.14	0.62	0.08	0.38	0.09	0.62
2024q1	0.22	0.33	0.04	0.20	0.02	0.10	0.03	0.20
2024q2	0.29	0.42	0.07	0.34	0.04	0.18	0.05	0.34
2024q3	0.36	0.50	0.13	0.45	0.08	0.29	0.08	0.45
2024q4	0.68	0.79	0.15	0.61	0.09	0.36	0.10	0.61
Mean	0.38	0.54	0.09	0.42	0.05	0.25	0.05	0.42

Table 8: Calibration of Preference Parameters and Risk Premia under Alternative Market-Segmentation Scenarios

This table reports calibrated preference parameters and risk-premium components under four market-segmentation scenarios, corresponding to different choices of $(\theta_{s,1}, \theta_{s,2})$. Panels A–C use the number-of-funds–based shares from Table 7: Panel A sets $(\theta_{s,1}, \theta_{s,2}) = (0.05, 0.40)$ using the "PRI & SLB Holder" definition; Panel B sets $(0.15, 0.25)$ using the narrow PRI definition; and Panel C sets $(0.25, 0.40)$ using the broad PRI definition. Panel D provides a benchmark specification with $(\theta_{s,1}, \theta_{s,2}) = (0.40, 0.50)$, where both shares are measured using PRI-based assets under management (AUM). For each scenario, results are shown for $\rho \in \{0, 0.3, -0.3\}$. Reported quantities include the calibrated preference parameters $(\tilde{\eta}, \tilde{\gamma})$, the sustainability and financial prices of risk (λ_x, λ_v), and the sustainability-related components of the equity premium: the reward term SRP_reward, the risk term SRP_risk, and their sum TSRP. We also report $\beta\lambda_x$ and $\beta\lambda_v$, the contributions of the two risk channels to the put-option payoff, as well as $w\beta\lambda_x$ and $w\beta\lambda_v$, which scale these by the option weight $w = 0.02$ following Table 6. $\beta = -3.63$ is calibrated as the panel-average conditional factor exposure. All risk premia are expressed in annualized percentage terms. The sample period is from September 2019 to August 2025.

ρ	$\tilde{\eta}$	$\tilde{\gamma}$	λ_x	λ_v	SRP_reward	SRP_risk	TSRP	$\beta\lambda_x$	$\beta\lambda_v$	$w\beta\lambda_x$	$w\beta\lambda_v$
Panel A: $(\theta_{s,1}, \theta_{s,2}) = (0.05, 0.40)$, Sustainable Investor Definition = PRI & SLB Holder (number of funds)											
0	1.95	3.55	7.60%	0.00%	-0.25%	0.26%	0.01%	-27.59%	0.00%	-0.55%	0.00%
0.3	1.05	3.54	4.08%	3.52%	-0.14%	0.18%	0.04%	-14.82%	-12.77%	-0.30%	-0.26%
-0.3	2.86	3.60	11.18%	-3.58%	-0.37%	0.27%	-0.09%	-40.58%	12.99%	-0.81%	0.26%
Panel B: $(\theta_{s,1}, \theta_{s,2}) = (0.15, 0.25)$, Sustainable Investor Definition = PRI (narrow, number of funds)											
0	3.11	3.16	7.60%	0.00%	-1.36%	2.24%	0.89%	-27.59%	0.00%	-0.69%	0.00%
0.3	1.75	3.35	4.27%	3.33%	-0.72%	1.19%	0.47%	-15.51%	-12.08%	-0.39%	-0.30%
-0.3	4.32	2.97	10.56%	-2.96%	-2.01%	3.31%	1.31%	-38.32%	10.74%	-0.96%	0.27%
Panel C: $(\theta_{s,1}, \theta_{s,2}) = (0.25, 0.40)$, Sustainable Investor Definition = PRI (broad, number of funds)											
0	1.95	3.54	7.60%	0.00%	-1.26%	1.31%	0.04%	-27.59%	0.00%	-0.69%	0.00%
0.3	1.07	3.46	4.16%	3.44%	-0.71%	0.93%	0.22%	-15.11%	-12.48%	-0.38%	-0.31%
-0.3	2.90	3.77	11.35%	-3.75%	-1.77%	1.29%	-0.48%	-41.20%	13.61%	-1.03%	0.34%
Panel D: $(\theta_{s,1}, \theta_{s,2}) = (0.40, 0.50)$, Sustainable Investor Definition = PRI (broad, AUM-based)											
0	1.56	3.68	7.60%	0.00%	-1.56%	1.29%	-0.27%	-27.59%	0.00%	-0.55%	0.00%
0.3	0.85	3.47	4.14%	3.46%	-0.90%	1.08%	0.18%	-15.04%	-12.54%	-0.30%	-0.25%
-0.3	2.40	4.14	11.72%	-4.12%	-2.13%	0.81%	-1.33%	-42.55%	14.96%	-0.85%	0.30%

Appendix A Derivation of the Equilibrium Pricing

A1 Derivation of Portfolio Allocation

At the individual level, a sustainable investor has exponential preferences as in equation (1). This representative investor has initial financial wealth W_0 and an initial sustainability endowment X_0. It is convenient to rewrite utility in terms of an augmented payoff:

$$U = -\exp\left(-\gamma Z\right), \qquad Z = W + \frac{\eta}{\gamma}X,$$
$$U = -\exp\left(-\gamma W_0\left(\frac{W}{W_0} + \frac{\eta X_0}{\gamma W_0}\frac{X}{X_0}\right)\right).$$

Let $\boldsymbol{p} = \left[p_1\ p_2\right]$ denote the price vector and $\boldsymbol{D}_p = \mathrm{diag}(p_1, p_2)$ the diagonal matrix of asset prices. The investor chooses portfolio weights $\boldsymbol{\omega}$ over the two risky assets and the risk-free asset. Let $\boldsymbol{R}_v = \boldsymbol{D}_p^{-1}\boldsymbol{V}$ denote the vector of financial (gross) returns on the two risky assets. The resulting terminal financial wealth is

$$W = W_0\, \boldsymbol{\omega}^\top \boldsymbol{R}_v.$$

Similarly, sustainability outcomes associated with the portfolio are proportional to the sustainability-payoff vector $\boldsymbol{X}$. Writing the sustainability payoff in currency units as $\boldsymbol{g}$, we have

$$X = W_0\, \boldsymbol{\omega}^\top \boldsymbol{D}_p^{-1}\boldsymbol{g} = X_0\, \frac{W_0}{X_0}\, \boldsymbol{\omega}^\top \boldsymbol{D}_p^{-1}\boldsymbol{X}.$$

Therefore, the portfolio induces a sustainability "growth-rate" payoff (in return units)

$$\boldsymbol{R}_x = \frac{W_0}{X_0}\, \boldsymbol{D}_p^{-1}\boldsymbol{X}, \qquad X = X_0\, \boldsymbol{\omega}^\top \boldsymbol{R}_x.$$

Using these definitions, wealth and sustainability can be expressed as

$$W = W_0 \cdot \left(\boldsymbol{\omega}^\top(\boldsymbol{R}_v - r_f \cdot \mathbf{1}) + r_f\right), \qquad X = X_0 \cdot \boldsymbol{\omega}^\top \boldsymbol{R}_x.$$

Define the scaled (relative) preference parameters

$$\tilde{\gamma} = \gamma W_0, \qquad \tilde{\eta} = \eta X_0.$$

Then utility can be written as

$$U = -\exp(-\tilde{\gamma} r_z), \tag{A1}$$

where the sustainability-augmented return is

$$r_z = \left(\boldsymbol{\omega}^\top(\boldsymbol{R}_v - r_f \cdot \mathbf{1}) + r_f\right) + \frac{\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{\omega}^\top \boldsymbol{R}_x.$$

The term r_z equals the portfolio's financial return plus the portfolio's sustainability return $\boldsymbol{\omega}^\top\boldsymbol{R}_x$, scaled by $\tilde{\eta}/\tilde{\gamma}$.
Under joint normality of $(\boldsymbol{R}_v, \boldsymbol{R}_x)$, r_z is normally distributed, so expected utility is

$$\mathbb{E}[U] = -\exp\left(-\tilde{\gamma} r_f - \tilde{\gamma}\mathbb{E}[r_z] + \frac{\tilde{\gamma}^2}{2}\mathrm{Var}(r_z)\right). \tag{A2}$$

Let $\boldsymbol{\mu}_R^v = \mathbb{E}[\boldsymbol{R}_v]$, $\boldsymbol{\Sigma}_R^v = \mathrm{Var}(\boldsymbol{R}_v)$, $\boldsymbol{\mu}_R^x = \mathbb{E}[\boldsymbol{R}_x]$, $\boldsymbol{\Sigma}_R^x = \mathrm{Var}(\boldsymbol{R}_x)$, and $\boldsymbol{C}_R^x = \mathrm{Cov}(\boldsymbol{R}_v, \boldsymbol{R}_x)$. Then

$$\mathbb{E}[r_z] = \boldsymbol{\omega}^\top\boldsymbol{\mu}_R^v + \frac{\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{\omega}^\top\boldsymbol{\mu}_R^x,$$

and

$$\mathrm{Var}(r_z) = \boldsymbol{\omega}^\top \boldsymbol{\Sigma}_R^v \boldsymbol{\omega} + \frac{\tilde{\eta}^2}{\tilde{\gamma}^2} \boldsymbol{\omega}^\top \boldsymbol{\Sigma}_R^x \boldsymbol{\omega} + 2\frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\omega}^\top \boldsymbol{C}_R^x \boldsymbol{\omega}.$$

Dropping constants, the investor's problem is equivalent to maximizing the mean–variance objective

$$\tilde{U}(\boldsymbol{\omega}) = \boldsymbol{\omega}^\top \left(\boldsymbol{\mu}_R^v - r_f \cdot \mathbf{1} + \frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\mu}_R^x \right) - \frac{1}{2} \tilde{\gamma}\, \boldsymbol{\omega}^\top \boldsymbol{\Sigma}_R^v \boldsymbol{\omega} - \frac{1}{2} \frac{\tilde{\eta}^2}{\tilde{\gamma}}\, \boldsymbol{\omega}^\top \boldsymbol{\Sigma}_R^x \boldsymbol{\omega} - \frac{\tilde{\eta}}{\tilde{\gamma}}\, \boldsymbol{\omega}^\top \boldsymbol{C}_R^x \boldsymbol{\omega}.$$

The optimal portfolio of the (representative) sustainable investor is therefore

$$\boldsymbol{\omega}_s = \tilde{\gamma}^{-1} \left(\boldsymbol{\Sigma}_R^v + \frac{\tilde{\eta}^2}{\tilde{\gamma}^2} \boldsymbol{\Sigma}_R^x + \frac{2\tilde{\eta}}{\tilde{\gamma}^2} \boldsymbol{C}_R^x \right)^{-1} \left(\boldsymbol{\mu}_R^v - r_f \cdot \mathbf{1} + \frac{\tilde{\eta}}{\tilde{\gamma}} \boldsymbol{\mu}_R^x \right).$$

A2 Equilibrium Price Solution

We now use the individual portfolio rules derived above to solve for equilibrium prices in the two risky-asset markets: the traditional (index) asset and the SLB-like insurance asset. Solving for equilibrium prices requires expressing the return-level moments in terms of payoff-level moments. Recall that

$$\boldsymbol{\mu}_R^v = \boldsymbol{D}_p^{-1} \boldsymbol{\mu}^v, \qquad \boldsymbol{\Sigma}_R^v = \boldsymbol{D}_p^{-1} \boldsymbol{\Sigma}^v \boldsymbol{D}_p^{-1}, \qquad \boldsymbol{\mu}_R^x = \frac{W_0}{X_0} \boldsymbol{D}_p^{-1} \boldsymbol{\mu}^x, \qquad \boldsymbol{\Sigma}_R^x = \left(\frac{W_0}{X_0} \right)^2 \boldsymbol{D}_p^{-1} \boldsymbol{\Sigma}^x \boldsymbol{D}_p^{-1},$$

and the cross-covariance in return space is

$$\boldsymbol{C}_R^x = \mathrm{Cov}(\boldsymbol{R}_v, \boldsymbol{R}_x) = \frac{W_0}{X_0} \boldsymbol{D}_p^{-1} \boldsymbol{C}^x \boldsymbol{D}_p^{-1}.$$

Using these relations, the portfolio weight of the individual sustainable investor can be written equivalently in payoff space as

$$\begin{aligned}
\boldsymbol{\omega}_s &= \tilde{\gamma}^{-1} \left[\boldsymbol{D}_p^{-1} \left(\boldsymbol{\Sigma}^v + \frac{\tilde{\eta}^2}{\tilde{\gamma}^2} \left(\frac{W_0}{X_0} \right)^2 \boldsymbol{\Sigma}^x + \frac{2\tilde{\eta}}{\tilde{\gamma}} \frac{W_0}{X_0} \boldsymbol{C}^x \right) \boldsymbol{D}_p^{-1} \right]^{-1} \boldsymbol{D}_p^{-1} \left(\boldsymbol{\mu}^v - r_f \boldsymbol{p} + \frac{\tilde{\eta}}{\tilde{\gamma}} \frac{W_0}{X_0} \boldsymbol{\mu}^x \right) \\
&= \tilde{\gamma}^{-1} \boldsymbol{D}_p \left[\boldsymbol{\Sigma}^v + \frac{\tilde{\eta}^2}{\tilde{\gamma}^2} \left(\frac{W_0}{X_0} \right)^2 \boldsymbol{\Sigma}^x + \frac{2\tilde{\eta}}{\tilde{\gamma}} \frac{W_0}{X_0} \boldsymbol{C}^x \right]^{-1} \left(\boldsymbol{\mu}^v - r_f \boldsymbol{p} + \frac{\tilde{\eta}}{\tilde{\gamma}} \frac{W_0}{X_0} \boldsymbol{\mu}^x \right) \\
&= \tilde{\gamma}^{-1} \boldsymbol{D}_p \left[\boldsymbol{\Sigma}^v + \frac{\eta^2}{\gamma^2} \boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma} \boldsymbol{C}^x \right]^{-1} \left(\boldsymbol{\mu}^v - r_f \boldsymbol{p} + \frac{\eta}{\gamma} \boldsymbol{\mu}^x \right), \qquad \text{(A3)}
\end{aligned}$$

where the last equality uses $\tilde{\gamma} = \gamma W_0$ and $\tilde{\eta} = \eta X_0$.

There is a continuum of two investor types—sustainable and conventional. All sustainable investors share the same relative preference parameters $(\tilde{\gamma}, \tilde{\eta})$. In addition, we assume that the ratio between initial financial wealth and initial sustainability endowment is identical across sustainable investors, that is, W_0/X_0 is common.

This normalization implies that the composite preference term

$$\frac{\tilde{\eta}^2}{\tilde{\gamma}^2} \left(\frac{W_0}{X_0} \right)^2 = \frac{\eta^2}{\gamma^2}$$

is the same for all sustainable investors. As a result, all sustainable investors face an identical mean–variance optimization problem and therefore choose the same optimal portfolio weights.

Similarly, we assume that all conventional investors share the same relative risk aversion coefficient $\tilde{\gamma}$ and therefore have a homogeneous portfolio allocation,

$$\boldsymbol{\omega}_c = \tilde{\gamma}^{-1} \boldsymbol{D}_p \left(\boldsymbol{\Sigma}^v \right)^{-1} \left(\boldsymbol{\mu}^v - r_f \boldsymbol{p} \right). \qquad \text{(A4)}$$

These assumptions are only aimed to take out unnecessary constants in solution and allows us to aggregate individual demands within each investor type without loss of generality.

To describe equilibrium pricing, we now move from individual investors to market-level wealth masses. Let $m \in \{1,2\}$ index the two risky-asset markets, where $m = 1$ denotes the traditional (index) asset and $m = 2$ the SLB asset. For each market m, let

$$W_{s,0}^{(m)}, \quad W_{c,0}^{(m)}$$

denote the total initial financial wealth of sustainable and conventional investors who are actively trading in that market.

Define the corresponding sustainable-capital share as

$$\theta_{s,m} = \frac{W_{s,0}^{(m)}}{W_{s,0}^{(m)} + W_{c,0}^{(m)}} \in (0,1), \qquad m = 1,2.$$

Here, $\theta_{s,1}$ represents the fraction of sustainable capital among all investors who trade the traditional asset, while $\theta_{s,2}$ is the analogous share in the SLB market.

Consistent with the segmentation patterns observed in the data, we have $W_{s,0}^{(1)} \ll W_{c,0}^{(1)}$, so that $\theta_{s,1}$ is close to zero in the traditional market. In contrast, sustainable capital represents a much larger share in the SLB market: $W_{s,0}^{(2)}$ is of comparable magnitude to $W_{c,0}^{(2)}$, implying a significantly higher value of $\theta_{s,2}$.

This segmentation arises from two empirical features. First, conventional investors exhibit limited participation in the SLB market, so that $W_{c,0}^{(2)} \ll W_{c,0}^{(1)}$. Second, while sustainable investors constitute a relatively small fraction of overall market wealth, they are disproportionately active in the SLB market, implying $W_{s,0}^{(2)} \gg W_{s,0}^{(1)}$. Together, these two forces generate a substantial wedge between $\theta_{s,1}$ and $\theta_{s,2}$.

The total wealth actively participating in each market reflects the interaction of these two opposing forces. For tractability, we assume that total active wealth is the same across markets, and denote it by

$$\bar{W} = W_{s,0}^{(m)} + W_{c,0}^{(m)}, \qquad m = 1,2.$$

This normalization eliminates unnecessary scale differences across markets while preserving the economically relevant heterogeneity in investor composition captured by $\theta_{s,1}$ and $\theta_{s,2}$.

Normalize the net supply of each risky asset to one. In market m, the demand for asset m in currency units equals the wealth of each investor type times their portfolio weights:

$$p_m = W_{s,0}^{(m)}\omega_{s,m} + W_{c,0}^{(m)}\omega_{c,m} = \bar{W}\big[\theta_{s,m}\omega_{s,m} + (1-\theta_{s,m})\omega_{c,m}\big],$$

where $\omega_{s,m}$ and $\omega_{c,m}$ denote the m-th components of $\boldsymbol{\omega}_s$ and $\boldsymbol{\omega}_c$, respectively.

This market-clearing condition assumes that investors who actively participate in both markets follow the portfolio allocation rules derived above. Market segmentation arises because a subset of investors participates in only one of the two markets. We assume that such investors follow the same portfolio allocation rule in the market they participate in, while assigning zero weight to the asset in the other market.

In practice, investors who participate exclusively in the traditional market may deviate from the benchmark portfolio rule derived above. We abstract from such heterogeneity to simplify the equilibrium solution and to highlight the role of the sustainable-capital share $\theta_{s,m}$ in shaping equilibrium prices. The underlying sources of market segmentation may include biased beliefs or information frictions, differences in investment mandates, or habitat-based demands. We do not take a stand on these microfoundations and instead treat $\theta_{s,m}$ as a reduced-form object capturing effective participation in each market.

Collecting the two markets in vector form, define the diagonal matrices

$$\boldsymbol{D}_\theta = \mathrm{diag}(\theta_{s,1}, \theta_{s,2}),$$

so the market-clearing condition can be written compactly as

$$\boldsymbol{p} = \bar{W}\left(\boldsymbol{D}_\theta\boldsymbol{\omega}_s + (\boldsymbol{I} - \boldsymbol{D}_\theta)\boldsymbol{\omega}_c\right). \tag{A5}$$

Equation (A5) shows that for each market the price equals total active wealth times the average portfolio weight, where the average is taken over sustainable and conventional investors with weights $\theta_{s,m}$ and $1-\theta_{s,m}$. Segmentation enters only through $\boldsymbol{D}_{\theta}$.
The market-clearing condition is,

$$\boldsymbol{p} = \bar{W}\boldsymbol{D_\theta}\tilde{\gamma}^{-1}\boldsymbol{D_p}\left[\boldsymbol{\Sigma}^v + \frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x\right]^{-1}\left(\boldsymbol{\mu}^v - r_f\boldsymbol{p} + \frac{\eta}{\gamma}\boldsymbol{\mu}^x\right) + \bar{W}\left((\boldsymbol{I}-\boldsymbol{D_\theta})\tilde{\gamma}^{-1}(\boldsymbol{\Sigma}^v)^{-1}(\boldsymbol{\mu}^v - r_f\boldsymbol{p})\right)$$

Divide a $\boldsymbol{D_p}$ for both sides,

$$\boldsymbol{1} = \tilde{\gamma}^{-1}\bar{W}\boldsymbol{D_\theta}\left[\boldsymbol{\Sigma}^v + \frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x\right]^{-1}\left(\boldsymbol{\mu}^v - r_f\boldsymbol{p} + \frac{\eta}{\gamma}\boldsymbol{\mu}^x\right) + \tilde{\gamma}^{-1}\bar{W}\left((\boldsymbol{I}-\boldsymbol{D_\theta})(\boldsymbol{\Sigma}^v)^{-1}(\boldsymbol{\mu}^v - r_f\boldsymbol{p})\right)$$

Define,

$$\boldsymbol{M} = \frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x$$

Re-organizing terms leads to,

$$\tilde{\gamma}\bar{W}^{-1}\boldsymbol{\Sigma}^v\boldsymbol{1} = \boldsymbol{D_\theta}\boldsymbol{\Sigma}^v(\boldsymbol{\Sigma}^v + \boldsymbol{M})^{-1}\left(\boldsymbol{\mu}^v - r_f\boldsymbol{p} + \frac{\eta}{\gamma}\boldsymbol{\mu}^x\right) + (\boldsymbol{I}-\boldsymbol{D_\theta})(\boldsymbol{\mu}^v - r_f\boldsymbol{p})$$

Define $A = \boldsymbol{D_\theta}\boldsymbol{\Sigma}^v(\boldsymbol{\Sigma}^v + \boldsymbol{M})^{-1} + (\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{I}$ and re-organize,

$$\boldsymbol{p}r_f = \boldsymbol{\mu}^v + \frac{\eta}{\gamma}\boldsymbol{\mu}^x - (\boldsymbol{I}-\boldsymbol{D_\theta})\frac{\eta}{\gamma}A^{-1}\boldsymbol{\mu}^x - \tilde{\gamma}\bar{W}^{-1}A^{-1}\boldsymbol{\Sigma}^v\boldsymbol{1}$$

Note that,

$$\boldsymbol{A} = [\boldsymbol{\Sigma}^v + (\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{M}][\boldsymbol{\Sigma}^v + \boldsymbol{M}]^{-1}$$

Here we need to take an approximation,

$$\boldsymbol{A}^{-1} \approx \boldsymbol{I} + \boldsymbol{D_\theta}\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}.$$

To see this, assuming

$$\left\|\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\right\| \approx 0,$$

where $\boldsymbol{M} = \frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x$. This implies that the covariance adjustments $\boldsymbol{M}$ are small relative to $\boldsymbol{\Sigma}^v$, allowing us to use a first-order Neumann series expansion for the inverse. Starting from the definition of $\boldsymbol{A}$:

$$\boldsymbol{A} = [\boldsymbol{\Sigma}^v + (\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{M}][\boldsymbol{\Sigma}^v + \boldsymbol{M}]^{-1},$$

we factor out $\boldsymbol{\Sigma}^v$ and approximate the inverse:

$$\boldsymbol{A}^{-1} = \left[\boldsymbol{I} + \boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\right]\left[\boldsymbol{I} + (\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\right]^{-1}.$$

Assuming $\|(\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\| \approx 0$, expand the inverse to first order:

$$\left[\boldsymbol{I} + (\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\right]^{-1} \approx \boldsymbol{I} - (\boldsymbol{I}-\boldsymbol{D_\theta})\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}.$$

Multiplying out and neglecting higher-order terms:

$$\boldsymbol{A}^{-1} \approx \boldsymbol{I} + \boldsymbol{D_\theta}\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}.$$

Substituting $\boldsymbol{A}^{-1}$ into the Price Formula gives,

$$\boldsymbol{p}r_f = \boldsymbol{\mu}^v + \frac{\eta}{\gamma}\boldsymbol{\mu}^x - \frac{\eta}{\gamma}(\boldsymbol{I} - \boldsymbol{D_\theta})\left(\boldsymbol{I} + \boldsymbol{D_\theta}\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\right)\boldsymbol{\mu}^x - \tilde{\gamma}\bar{W}^{-1}\left(\boldsymbol{I} + \boldsymbol{D_\theta}\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}\right)\boldsymbol{\Sigma}^v\boldsymbol{1}.$$

Ignore the term proportional to $\boldsymbol{M}(\boldsymbol{\Sigma}^v)^{-1}$ and simplify the result.

$$\boldsymbol{p}r_f = \boldsymbol{\mu}^v + \boldsymbol{D_\theta}\frac{\eta}{\gamma}\boldsymbol{\mu}^x - \tilde{\gamma}\bar{W}^{-1}\boldsymbol{\Sigma}^v\boldsymbol{1} - \tilde{\gamma}\bar{W}^{-1}\boldsymbol{D_\theta}\boldsymbol{M}\boldsymbol{1}.$$

Substitute the definition of $\boldsymbol{M}$,

$$\boldsymbol{p} = \frac{1}{r_f}\left[\boldsymbol{\mu}^v + \boldsymbol{D_\theta}\frac{\eta}{\gamma}\boldsymbol{\mu}^x - \tilde{\gamma}\bar{W}^{-1}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x\right)\right)\cdot\boldsymbol{1}\right]$$

A3 Risk Premium Solution

Divide both side by $\boldsymbol{D_p}$, then,

$$\boldsymbol{1}\cdot r_f = \boldsymbol{D_p}^{-1}\left[\boldsymbol{\mu}^v + \boldsymbol{D_\theta}\frac{\eta}{\gamma}\boldsymbol{\mu}^x - \tilde{\gamma}\bar{W}^{-1}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x\right)\right)\cdot\boldsymbol{1}\right]$$

Then,

$$\boldsymbol{D_p}^{-1}\boldsymbol{\mu}^v - r_f\cdot\boldsymbol{1} = \boldsymbol{D_p}^{-1}\left[\tilde{\gamma}\bar{W}^{-1}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\eta^2}{\gamma^2}\boldsymbol{\Sigma}^x + \frac{2\eta}{\gamma}\boldsymbol{C}^x\right)\right)\cdot\boldsymbol{1} - \boldsymbol{D_\theta}\frac{\eta}{\gamma}\boldsymbol{\mu}^x\right]$$

We now transfer the mean and covariance at payoff-level back to return-level.

$$\begin{aligned}\boldsymbol{\mu}_R^v - r_f\cdot\boldsymbol{1} &= \boldsymbol{D_p}^{-1}\left[\tilde{\gamma}\bar{W}^{-1}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}^2}\left(\frac{W_{s,0}}{X_0}\right)^2\boldsymbol{\Sigma}^x + \frac{2\tilde{\eta}}{\tilde{\gamma}}\frac{W_{s,0}}{X_0}\boldsymbol{C}^x\right)\right)\cdot\boldsymbol{1} - \boldsymbol{D_\theta}\frac{\eta}{\gamma}\boldsymbol{\mu}^x\right]\\ &= \boldsymbol{D_p}^{-1}\left[\tilde{\gamma}\bar{W}^{-1}\boldsymbol{D_p}\boldsymbol{D_p}^{-1}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}^2}\left(\frac{W_{s,0}}{X_0}\right)^2\boldsymbol{\Sigma}^x + \frac{2\tilde{\eta}}{\tilde{\gamma}}\frac{W_{s,0}}{X_0}\boldsymbol{C}^x\right)\right)\boldsymbol{D_p}^{-1}\boldsymbol{D_p}\cdot\boldsymbol{1}\right] - \boldsymbol{D_p}^{-1}\boldsymbol{D_\theta}\frac{\eta}{\gamma}\frac{W_{s,0}}{X_0}\boldsymbol{\mu}^x\end{aligned}$$

The scale of $\boldsymbol{D_p}^{-1}$ transfer the payoff-level mean and variance back to return-level. And the absolute risk aversion coefficients are transformed back to relative risk averison.

$$\boldsymbol{\mu}_R^v - r_f\cdot\boldsymbol{1} = \boldsymbol{D_p}^{-1}\left[\tilde{\gamma}\bar{W}^{-1}\boldsymbol{D_p}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}^2}\boldsymbol{\Sigma_g} + \frac{2\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{C_g}\right)\right)\cdot\mathbf{p}\right] - \boldsymbol{D_\theta}\frac{\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{\mu}_R^x$$

Define the market weight of each asset by,

$$\omega_1 = p_1/\bar{W},\ \omega_2 = p_2/\bar{W}$$

Then,

$$\boldsymbol{\mu}_R^v - r_f\cdot\boldsymbol{1} = \tilde{\gamma}\boldsymbol{D_p}^{-1}\boldsymbol{D_\omega}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}^2}\boldsymbol{\Sigma^x} + \frac{2\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{C^x}\right)\right)\cdot\mathbf{p} - \boldsymbol{D_\theta}\frac{\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{\mu}_R^x$$

where $\boldsymbol{D_\omega}$ is a diagonal matrix of ω_1, ω_2. In addition,

$$\boldsymbol{D_p}^{-1}\boldsymbol{D_\omega}\left(\boldsymbol{\Sigma}^v + \boldsymbol{D_\theta}\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}^2}\boldsymbol{\Sigma^x} + \frac{2\tilde{\eta}}{\tilde{\gamma}}\boldsymbol{C^x}\right)\right)\cdot\mathbf{p} = \begin{bmatrix} p_1^{-1}\omega_1\left(\tilde{\sigma}_v^2 + \theta_{s,1}\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}^2}\tilde{\sigma}_x^2 + \frac{2\tilde{\eta}}{\tilde{\gamma}}\rho\tilde{\sigma}_v\tilde{\sigma}_x\right)\right) & p_1^{-1}\omega_1\beta\rho\tilde{\sigma}_v\tilde{\sigma}_x \\ p_2^{-1}\omega_2\left(\beta\rho\tilde{\sigma}_v\tilde{\sigma}_x + \theta_{s,2}\frac{2\tilde{\eta}}{\tilde{\gamma}}\beta\tilde{\sigma}_x^2\right) & p_2^{-1}\omega_2\beta^2\tilde{\sigma}_x^2\end{bmatrix}\begin{bmatrix}p_1\\p_2\end{bmatrix}$$

And

$$\omega_1/\omega_2 = p_1/p_2.$$

Then the expected returns are solved as follows,

$$\tilde{\mu}_1 - R_f = -\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\tilde{\mu}_x + \theta_{s,1}\omega_1\left(\frac{\tilde{\eta}^2}{\tilde{\gamma}}\tilde{\sigma}_x^2 + 2\tilde{\eta}\rho\tilde{\sigma}_v\tilde{\sigma}_x\right) + \omega_1\tilde{\gamma}\tilde{\sigma}_v^2 + \omega_2\tilde{\gamma}\beta\rho\tilde{\sigma}_v\tilde{\sigma}_x,$$

$$\tilde{\mu}_2 - R_f = \theta_{s,2}\omega_1\left(\beta\tilde{\sigma}_x^2 2\tilde{\eta}\right) + \omega_1\tilde{\gamma}\beta\rho\tilde{\sigma}_v\tilde{\sigma}_x + \omega_2\tilde{\gamma}\beta^2\tilde{\sigma}_x^2.$$

Setting $\omega_1 = 1$ and $\omega_2 = 0$ yields the factor presentation shown in the main text. Define the sustainability risk premium as

$$\lambda_x = \theta_{s,2}\, 2\tilde{\eta}\tilde{\sigma}_x^2, \tag{A6}$$

and the traditional risk premium as

$$\lambda_v = \tilde{\gamma}\,\rho\,\tilde{\sigma}_v\,\tilde{\sigma}_x. \tag{A7}$$

Then we obtain

$$\tilde{\mu}_2 - R_f = \omega_1\beta\lambda + \omega_2\tilde{\gamma}\beta^2\tilde{\sigma}_x^2 \approx \beta\lambda, \tag{A8}$$

where

$$\lambda = \lambda_x + \lambda_v. \tag{A9}$$

The corresponding expected return for the market index asset is

$$\tilde{\mu}_1 - r_f = \underbrace{-\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\tilde{\mu}_x}_{\text{non-pecuniary preference reward}} + \underbrace{\frac{1}{2}\frac{\theta_{s,1}}{\theta_{s,2}}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_x}_{\text{sustainability risk premium}} + \underbrace{2\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\lambda_v + \tilde{\gamma}\tilde{\sigma}_v^2}_{\text{traditional risk premium}}. \tag{A10}$$

A4 Calibration of Values Preference

We calibrate $(\tilde{\eta}, \tilde{\gamma})$ taking as given the total price of risk λ (from SLB returns), the capital shares $(\theta_{s,1}, \theta_{s,2})$, and the moments $(\tilde{\mu}_1 - r_f, \tilde{\mu}_x, \tilde{\sigma}_v, \tilde{\sigma}_x, \rho)$. Use

$$\tilde{\mu}_2 - r_f = \beta\,\lambda, \qquad \lambda = \lambda_x + \lambda_v \quad \text{with} \quad \lambda_x = 2\theta_{s,2}\tilde{\eta}\tilde{\sigma}_x^2, \quad \lambda_v = \tilde{\gamma}\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x,$$

and

$$\tilde{\mu}_1 - r_f = -\theta_{s,1}\frac{\tilde{\eta}}{\tilde{\gamma}}\tilde{\mu}_x + \theta_{s,1}\frac{\tilde{\eta}^2}{\tilde{\gamma}}\,\tilde{\sigma}_x^2 + 2\theta_{s,1}\tilde{\eta}\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x + \tilde{\gamma}\tilde{\sigma}_v^2.$$

$$\tilde{\gamma}\,(\tilde{\mu}_1 - r_f) = -\theta_{s,1}\tilde{\eta}\tilde{\mu}_x + \theta_{s,1}\tilde{\eta}^2\,\tilde{\sigma}_x^2 + 2\theta_{s,1}\tilde{\gamma}\tilde{\eta}\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x + \tilde{\gamma}^2\tilde{\sigma}_v^2.$$

From $\lambda = \lambda_x + \lambda_v$,

$$\lambda \;=\; 2\theta_{s,2}\tilde{\eta}\tilde{\sigma}_x^2 + \tilde{\gamma}\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x \quad\Rightarrow\quad \tilde{\eta} \;=\; \frac{\lambda - \tilde{\gamma}\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x}{2\theta_{s,2}\tilde{\sigma}_x^2} = \frac{\lambda}{2\theta_{s,2}\tilde{\sigma}_x^2} - \frac{\rho\,\tilde{\sigma}_v\tilde{\sigma}_x}{2\theta_{s,2}\tilde{\sigma}_x^2}\tilde{\gamma}. \tag{A11}$$

Substitute this expression into the expected return condition:

$$\tilde{\gamma}(\tilde{\mu}_1 - r_f) = -\theta_{s,1}\tilde{\eta}\tilde{\mu}_x + \theta_{s,1}\tilde{\eta}^2\,\tilde{\sigma}_x^2 + 2\theta_{s,1}\tilde{\gamma}\tilde{\eta}\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x + \tilde{\gamma}^2\tilde{\sigma}_v^2.$$

Step by step, each term becomes:

$$-\theta_{s,1}\tilde{\eta}\tilde{\mu}_x = -\theta_{s,1}\tilde{\mu}_x\frac{\lambda}{2\theta_{s,2}\tilde{\sigma}_x^2} + \theta_{s,1}\tilde{\mu}_x\frac{\rho\,\tilde{\sigma}_v\tilde{\sigma}_x}{2\theta_{s,2}\tilde{\sigma}_x^2}\tilde{\gamma},$$

$$\theta_{s,1}\tilde{\eta}^2\tilde{\sigma}_x^2 = \frac{\theta_{s,1}\lambda^2}{4\theta_{s,2}^2\tilde{\sigma}_x^2} - \frac{\theta_{s,1}\lambda\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x}{2\theta_{s,2}^2\tilde{\sigma}_x^2}\tilde{\gamma} + \frac{\theta_{s,1}\rho^2\tilde{\sigma}_v^2}{4\theta_{s,2}^2}\tilde{\gamma}^2,$$

$$2\theta_{s,1}\tilde{\gamma}\tilde{\eta}\rho\,\tilde{\sigma}_v\tilde{\sigma}_x = \frac{\theta_{s,1}\lambda\,\rho\,\tilde{\sigma}_v\tilde{\sigma}_x}{\theta_{s,2}\tilde{\sigma}_x^2}\tilde{\gamma} - \frac{\theta_{s,1}\rho^2\tilde{\sigma}_v^2}{\theta_{s,2}}\tilde{\gamma}^2,$$

$$\tilde{\gamma}^2\tilde{\sigma}_v^2 \text{ remains unchanged.}$$

Collect terms by powers of $\tilde{\gamma}$:

$$Q\,\tilde{\gamma}^2 + L\,\tilde{\gamma} + C = 0,$$

where

$$C = \frac{\theta_{s,1}\lambda(\lambda - 2\theta_{s,2}\tilde{\mu}_x)}{4\theta_{s,2}^2\tilde{\sigma}_x^2},$$

$$L = \frac{\theta_{s,1}\rho\,\tilde{\sigma}_v}{2\theta_{s,2}^2\tilde{\sigma}_x}\Big[\theta_{s,2}\tilde{\mu}_x + \lambda(2\theta_{s,2} - 1)\Big] - (\tilde{\mu}_1 - r_f),$$

$$Q = \tilde{\sigma}_v^2\Big[\,1 + \frac{\theta_{s,1}\rho^2(1 - 4\theta_{s,2})}{4\theta_{s,2}^2}\Big].$$

Multiplying both sides by $4\theta_{s,2}^2\tilde{\sigma}_x^2$ to clear denominators gives

$$A_2\tilde{\gamma}^2 + A_1\tilde{\gamma} + A_0 = 0,$$

with coefficients

$$\begin{aligned}
A_2 &= 4\theta_{s,2}^2\tilde{\sigma}_x^2\tilde{\sigma}_v^2 + \theta_{s,1}\rho^2\tilde{\sigma}_v^2\tilde{\sigma}_x^2(1 - 4\theta_{s,2}),\\
A_1 &= 2\theta_{s,1}\rho\,\tilde{\sigma}_v\tilde{\sigma}_x\big[\theta_{s,2}\tilde{\mu}_x + \lambda(2\theta_{s,2} - 1)\big] - 4\theta_{s,2}^2\tilde{\sigma}_x^2(\tilde{\mu}_1 - r_f),\\
A_0 &= \theta_{s,1}\lambda(\lambda - 2\theta_{s,2}\tilde{\mu}_x).
\end{aligned}$$

Solving the quadratic yields

$$\tilde{\gamma} = \frac{-A_1 \pm \sqrt{A_1^2 - 4A_2A_0}}{2A_2},$$

and the economically meaningful (positive) root is selected. Finally, recover

$$\tilde{\eta} = \frac{\lambda}{2\theta_{s,2}\tilde{\sigma}_x^2} - \frac{\rho\,\tilde{\sigma}_v\tilde{\sigma}_x}{2\theta_{s,2}\tilde{\sigma}_x^2}\tilde{\gamma}.$$

A simple special case is when $\rho = 0$. Then,

$$\tilde{\eta} \approx \frac{\lambda_x}{2\theta_{s,2}\tilde{\sigma}_x^2}.$$

Then we can solve $\tilde{\gamma}$ as follows,

$$\tilde{\gamma} = \frac{(\tilde{\mu}_1 - r_f) + \sqrt{(\tilde{\mu}_1 - r_f)^2 - 4\tilde{\sigma}_v^2\left(-\tilde{\eta}\tilde{\mu}_x + \tilde{\eta}^2\tilde{\sigma_x}^2\right)\theta_{s,1}}}{2\tilde{\sigma}_v^2}.$$

Appendix B Option Pricing

B1 Single-asset Case

We assume that sustainability performance x_t and financial value v_t follows a Geometric Brownian Motion, similar to the traditional payoff x in the single-period model:

$$\frac{dx_t}{x_t} = \tilde{\mu}_x \, dt + \tilde{\sigma}_x \, dB_t^x. \tag{B1}$$

$$\frac{dv_t}{v_t} = \tilde{\mu}_v \, dt + \tilde{\sigma}_v \, dB_t^v. \tag{B2}$$

And the innovation of firm fundamental and sustainability have correlation ρ.

$$\text{Cov}(dB_t^v, dB_t^x) = \rho dt. \tag{B3}$$

We apply the standard no-arbitrage pricing to the sustainability put option P_t. Under no-arbitrage, there exists a pricing kernel such that $E[\pi_t P_t]$ and $E^Q[e^{-r_f t} P_t]$ are martingales. The pricing kernel implies a risk-neutral measure such that,

$$P_t = \mathbb{E}_t^Q[1_{x_t<K}] \cdot Sp \cdot e^{-r_f (T-t)}.$$

We assume a parametric specification of such a pricing kernel,

$$\frac{d\pi_t}{\pi_t} = -r_f \, dt - a_v \, dB_t^v - a_x \, dB_t^x. \tag{B4}$$

Since $E[\pi_t P_t]$ is a martingale, we have:

$$\frac{d(\pi_t P_t)}{\pi_t P_t} = \frac{dP_t}{P_t} + \frac{d\pi_t}{\pi_t} + \text{Cov}\left(\frac{dP_t}{P_t}, \frac{d\pi_t}{\pi_t}\right).$$

The valuation PDE becomes:

$$-r_f P_t + \frac{\partial P_t}{\partial t} + 0.5 \frac{\partial^2 P_t}{\partial x_t^2} \tilde{\sigma}_x^2 x_t^2 + \frac{\partial P_t}{\partial x_t} x_t \tilde{\mu}_x - \text{Cov}(-\frac{d\pi_t}{\pi_t}, dP_t) = 0.$$

Using the dynamics of P_t:

$$dP_t = \left[\frac{\partial P_t}{\partial t} + \frac{\partial P_t}{\partial x_t} x_t \tilde{\mu}_x + 0.5 \frac{\partial^2 P_t}{\partial x_t^2} \tilde{\sigma}_x^2 x_t^2\right] dt + \frac{\partial P_t}{\partial x_t} \tilde{\sigma}_x x_t dB_t^x,$$

and substituting back, the equation becomes:

$$-r_f P_t + \frac{\partial P_t}{\partial t} + 0.5 \frac{\partial^2 P_t}{\partial x_t^2} \tilde{\sigma}_x^2 x_t^2 + \frac{\partial P_t}{\partial x_t} x_t \left[\tilde{\mu}_x - \text{Cov}(a_v \tilde{\sigma}_v \, dB_t^v + a_x \tilde{\sigma}_x \, dB_t^x, \tilde{\sigma}_x dB_t^x)\right] = 0.$$

Under the risk-neutral measure Q, since $E^Q[e^{-r_f t} P_t]$ is a martingale:

$$-r_f P_t + \frac{\partial P_t}{\partial t} + 0.5 \frac{\partial^2 P_t}{\partial x_t^2} \tilde{\sigma}_x^2 x_t^2 + \frac{\partial P_t}{\partial x_t} x_t \tilde{\mu}_x^Q = 0.$$

Combining these results gives:

$$\tilde{\mu}_x^Q = \tilde{\mu}_x - \text{Cov}(a_v \, dB_t^v + a_x \, dB_t^x, \tilde{\sigma}_x dB_t^x).$$

The loading coefficients a_x, a_v depend on the equilibrium setting. We adopt the equilibrium setting in the discrete time model and set the loading coefficients to match risk premiums derived in Proposition 3, such that,

$$\lambda = \tilde{\mu}_x - \tilde{\mu}_x^Q = \text{Cov}(a_v\, dB_t^v + a_x\, dB_t^x, \tilde{\sigma}_x dB_t^x) = \theta_{s,2}\, 2\tilde{\eta}\, \tilde{\sigma}_x^2 + \tilde{\gamma}\, \rho\, \tilde{\sigma}_v\, \tilde{\sigma}_x.$$

Rearranging yields:

$$\frac{\partial P_t}{\partial t} + \frac{\partial P_t}{\partial x_t} x_t \mu + 0.5 \frac{\partial^2 P_t}{\partial x_t^2} \tilde{\sigma}_x^2 x_t^2 = r_f P_t + \frac{\partial P_t}{\partial x_t} x_t \lambda.$$

Finally, substituting this into the dynamics:

$$\frac{dP_t}{P_t} - r_f = \left[\frac{\partial P_t}{\partial x_t} \frac{x_t}{P_t} \lambda\right] dt + \frac{\partial P_t}{\partial x_t} \frac{x_t}{P_t} \tilde{\sigma}_x dB_t^x.$$

Thus, the expected return on P_t, relative to the risk-free rate, depends on the term $\frac{\partial P_t}{\partial x_t} \frac{x_t}{P_t} \lambda$, with the conditional factor exposure,

$$\beta_t = \frac{\partial P_t}{\partial x_t} \frac{x_t}{P_t},$$

which depends on the solution of P_t.

P_t is then solved based on the risk-netural measure expectation, similar to the classical Black-Scholes formula.

$$P_t = Sp \cdot e^{-r_f (T-t)} \cdot N(-e_t), \tag{B5}$$

where:

$$e_t = \frac{\ln(x_t/K) + (\tilde{\mu}_x - \lambda)(T-t) - \frac{1}{2}\tilde{\sigma}_x^2 (T-t)}{\tilde{\sigma}_x \sqrt{T-t}}. \tag{B6}$$

Taking derivatives with respect to x_t further solves β_t and the solution reveals its relation with λ,

$$\beta_t(\lambda) = \frac{n(e_t)}{N(e_t)} \cdot \frac{-1}{\tilde{\sigma}_x \sqrt{T-t}} < 0, \tag{B7}$$

B2 Option Pricing and Equilibrium Interpretation

In our equilibrium model, we build a single-period environment such that SLB return equals βr_x. And in such environment, due to asset allocation of conventional investors and sustainable investors, the expected return of this asset equals $\beta\lambda$ in equilibrium, such that,

$$\lambda = \tilde{\mu}_x - \tilde{\mu}_x^Q = \text{Cov}(a_v\, dB_t^v + a_x\, dB_t^x, \tilde{\sigma}_x dB_t^x) = \theta_{s,2}\, 2\tilde{\eta}\, \tilde{\sigma}_x^2 + \tilde{\gamma}\, \rho\, \tilde{\sigma}_v\, \tilde{\sigma}_x.$$

Following the same idea, we provide conditions that describe a continuous trading economy, such that the expected return of put option is driven by the same λ, and

$$\mathbb{E}_t\left[\frac{dP_t}{P_t}\right] - r_f\, dt = \beta_t(\lambda)\, \lambda\, dt.$$

1. **Asset space.** There is a risk-free asset with constant return r_f; a market–index asset that delivers returns in both financial and sustainability dimensions (as in equation (16)); and a sustainability put option—an aggregate proxy for SLBs—whose return satisfies the conditional factor form in (22). At any instant, investors know the current $\beta_t(\lambda)$ associated with this option and use it to hedge potential downturns in sustainability growth.

2. **Contracts rolling over.** The sustainability put option exists as a continuously renewed series of contracts. When an existing SLB contract reaches maturity, its exposure $\beta_t(\lambda) \to 0$ and it expires. A new contract is immediately issued, restoring market exposure to sustainability risk.

3. **Market structure.** At each date, two investor types trade the two risky assets over an infinite horizon, and only a fraction ϕ_c of conventional investors participates in the SLB market (limited participation is persistent over time).

4. **Preferences and trading.** Investors have power utility over financial wealth and sustainability outcomes of the form $W_t^{-\tilde{\gamma}} X_t^{-\tilde{\eta}}$ ($\tilde{\eta} = 0$ for conventional investors), and both types trade dynamically.

These conditions describe an economy in which the maturity of the put option does not matter: new contracts roll over to provide continuous conditional exposure to sustainability growth. As a result, investors do not differ by investment horizon, and the dynamic portfolio problem collapses to a single–period problem because the underlying state variables v_t and x_t feature i.i.d. growth rates. The use of power utility accommodates log–normal (rather than normal) payoffs in continuous time, which is standard in the literature. Taken together, this setting reproduces the same portfolio allocation rules—and hence the same risk–premium implications—as in the single–period model.

Notably, even within this i.i.d. setting, expected returns in both SLBs and the aggregate traditional asset are time–varying for two reasons. First, sustainable capital concentrations $\theta_{s,1}$ and $\theta_{s,2}$ evolve with fluctuations in asset returns. Second, the SLB's conditional exposure varies with the moneyness and time to maturity of the put option. A more comprehensive theoretical environment can build on this baseline to incorporate additional realistic features (e.g., stochastic volatility or time–varying participation in the SLB market).

We now prove the Proposition 4. According to our model, the sustainability risk premium in the put option is,

$$\mathcal{F}_t = \mathrm{E_t}\left[\frac{dP_t}{P_t}\right] - r_f\, dt = \beta_t(\lambda)\cdot\lambda\, dt. \tag{B8}$$

We present λ as a function of $\theta_{s,2}$ and $\tilde{\eta}$, such that,

$$\lambda = \theta_{s,2}\, 2\tilde{\eta}\, \tilde{\sigma}_x^2 + \tilde{\gamma}\, \rho\, \tilde{\sigma}_v\, \tilde{\sigma}_x.$$

$$e_t = \frac{\ln(x_t/K) + (\tilde{\mu}_x - \lambda(\theta_{s,2},\tilde{\eta}))(T-t) - \frac{1}{2}\tilde{\sigma}_x^2(T-t)}{\tilde{\sigma}_x\sqrt{T-t}}.$$

We plug in the relation in equation (B7) use the product and chain rule to compute the derivative:

$$\frac{\partial \mathcal{F}}{\partial \theta_{s,2}} = \frac{\partial \mathcal{F}}{\partial e_t}\cdot\frac{\partial e_t}{\partial \lambda}\cdot\frac{\partial \lambda}{\partial \theta_{s,2}} + \frac{\partial \mathcal{F}}{\partial \lambda}\cdot\frac{\partial \lambda}{\partial \theta_{s,2}}$$

$$= \left(-\frac{\partial}{\partial e_t}\left[\frac{n(e_t)}{N(e_t)}\right]\cdot\frac{\partial e_t}{\partial \lambda}\cdot\frac{\partial \lambda}{\partial \theta_{s,2}}\right)\cdot\frac{1}{\tilde{\sigma}_x\sqrt{T-t}}\cdot\lambda(\theta_{s,2}) + \left(-\frac{n(e_t)}{N(e_t)}\cdot\frac{1}{\tilde{\sigma}_x\sqrt{T-t}}\cdot\frac{\partial \lambda}{\partial \theta_{s,2}}\right) + \left(-\lambda\cdot\frac{1}{\tilde{\sigma}_x\sqrt{T-t}}\cdot\frac{d}{d\lambda}\left(\frac{n(e_t)}{N(e_t)}\right)\right)$$

Notice that, $\frac{n(e_t)}{N(e_t)}$, the inverse Mills ratio, is strictly decreasing in e_t, and e_t is decreasing in λ:

$$\frac{de_t}{d\lambda} = -\frac{T-t}{\tilde{\sigma}_x\sqrt{T-t}} < 0,$$

$$\frac{d}{d\lambda}\left(\frac{n(e_t)}{N(e_t)}\right) = \frac{d}{de_t}\left(\frac{n(e_t)}{N(e_t)}\right)\cdot\frac{de_t}{d\lambda} > 0$$

In addition, λ is increasing in $\theta_{s,2}$:

$$\frac{d\lambda}{d\theta_{s,2}} = 2\tilde{\eta}\tilde{\sigma}_x^2 > 0.$$

Therefore, all three terms are negative and we can conclude that,

$$\frac{d\mathcal{F}}{d\theta_{s,2}} < 0.$$

Notice that $\tilde{\eta}$ also affects the risk premium through λ, the proof for $\tilde{\eta}$ can be done following exactly the same steps.

B3 Multiple-asset Case

The single-asset solution can be extended to any SLB put option with a firm specific sustainability performance,

$$\frac{dx_t(i)}{x_t(i)} = \tilde{\mu}_x(i)dt + \tilde{\sigma}^x(i)dB_t(i). \tag{B9}$$

Following the same no-arbitrage pricing approach, we assume that the pricing kernel loads on a common component in individual sustainability growth $\tilde{\sigma}^x(i)dB_t(i)$, i.e. a systematic factor of sustainbility growth, such that,

$$\frac{d\pi_t}{\pi_t} = -r_f\, dt - a_F^v dF_t^v - a_F^x dF_t^x. \tag{B10}$$

In this case, investors optimization can be considered as a two-step procedure: Investors firstly find the optimal portfolio for all the traditional assets and all the SLBs. This step typically involves the diversification of idiosyncratic risks and form a "market portfolio" of traditional asset, as well as SLB, driven by the systematic risk factor dF_t^v, dF_t^x. The second step is conceptually the same with our two-asset model, where investors allocate between an market index asset the SLB market portfolio.

The sustainability risk premium in each SLB comes from,

$$\lambda(i) = \mathrm{Cov}(a_F^v dF_t^v + a_F^x dF_t^X, \tilde{\sigma}_x(i)dB_t(i))$$

The derivation for risk-neutral pricing based on (B9) is the same as the single-asset, except using the common drift shifting

$$\lambda(i) = \tilde{\mu}_x(i) - \tilde{\mu}_x^Q(i)$$

for every asset.

$$\frac{dP_t(i)}{P_t(i)} - r_f\, dt = \beta_{i,t}(\lambda(i)) \cdot (\lambda(i)\, dt + \tilde{\sigma}_x(i)\, dB_t^x(i)) \tag{B11}$$

where $\beta_{i,t}(\lambda(i)) = \frac{\partial P_t(i)}{\partial x_t(i)} \frac{x_t(i)}{P_t(i)}$ is determined by each issuer's sustainability dynamics and its own sustainability risk premium $\lambda(i)$. Specifically,

$$\beta_{i,t}(\lambda(i)) = \frac{n(e_t(i))}{N(e_t(i))} \cdot \frac{-1}{\tilde{\sigma}_x(i)\sqrt{T-t}} < 0, \tag{B12}$$

where

$$e_t(i) = \frac{\ln(x_t(i)/K(i)) + (\tilde{\mu}_x(i) - \lambda(i))\,(T(i)-t) - \frac{1}{2}\tilde{\sigma}_x(i)^2(T(i)-t)}{\tilde{\sigma}_x(i)\sqrt{T(i)-t}}. \tag{B13}$$

B4 Approximate All Put Option Returns with a Common λ

Based on the specification of the pricing kernel in equation (B10), we define the systematic sustainability risk premium as

$$\lambda = \frac{1}{I}\sum_{i=1}^{I} \lambda(i) = \mathrm{Cov}\left(a_F^v dF_t^v + a_F^x dF_t^x, \frac{1}{I}\sum_{i=1}^{I} \tilde{\sigma}_x(i)\, dB_t(i)\right). \tag{B14}$$

Since idiosyncratic components in sustainability growth can be diversified,

$$\frac{1}{I}\sum_{i=1}^{I} \tilde{\sigma}_x(i)\, dB_t(i) \approx dF_t^x.$$

In this case, λ captures the systematic sustainability risk premium in SLBs. Consistent with our equilibrium setting, when investors trade the aggregate SLB market, the same λ drives the market-wide sustainability risk premium and has an identical economic interpretation:

$$\lambda = a_F^x\, \mathrm{Var}(dF_t^x) + a_F^v\, \mathrm{Cov}(dF_t^x, dF_t^v).$$

If we interpret dF_t^x and dF_t^v as the returns on the market index assets in our equilibrium framework, this λ corresponds exactly to the decomposition $\lambda = \lambda_v + \lambda_x$ derived earlier.

We now show that the summed sustainability risk premium across all SLBs can be well approximated by a single common λ, namely,

$$\sum_{i=1}^{I} \beta_{i,t}(\lambda(i))\,\lambda(i) \;\approx\; \sum_{i=1}^{I} \beta_{i,t}(\lambda)\,\lambda, \qquad \forall\, t.$$

For notational simplicity, we omit the time subscript t in the following derivations. Each issuer's risk premium is decomposed as

$$\lambda(i) = \lambda + \tilde{\lambda}_i, \tag{B15}$$

where λ is the common market-wide component and $\tilde{\lambda}_i$ is an issuer-specific deviation. From the definition of λ in (B14), these deviations satisfy

$$\sum_{i=1}^{I} \tilde{\lambda}_i = 0,$$

implying that issuer-specific components offset each other in the aggregate.

We approximate each bond's risk premium term $\beta_i(\lambda(i))\lambda(i)$ by a first-order Taylor expansion around the common λ:

$$\beta_i(\lambda(i))\lambda(i) = \beta_i(\lambda)\lambda + \Gamma_i\,\tilde{\lambda}_i + O(\tilde{\lambda}_i^2), \tag{B16}$$

where the second-order term $O(\tilde{\lambda}_i^2)$ is negligible when $\tilde{\lambda}_i$ is small. The first-order coefficient is

$$\Gamma_i \;\equiv\; \frac{\partial}{\partial\lambda}\big[\beta_i(\lambda)\,\lambda\big]\Big|_{\lambda=\lambda} \;=\; \beta_i(\lambda) \;+\; \lambda\,\beta_i'(\lambda). \tag{B17}$$

We next compute $\beta_i'(\lambda)$ and evaluate it at λ. From (B12),

$$\beta_i(\lambda) = -\frac{1}{\tilde{\sigma}_x(i)\sqrt{\tau_i}}\,\frac{n\big(e_i(\lambda)\big)}{N\big(e_i(\lambda)\big)}, \qquad e_i(\lambda) = \frac{\ln\big(x_t(i)/K(i)\big) + (\tilde{\mu}_x(i) - \lambda)\tau_i - \frac{1}{2}\tilde{\sigma}_x(i)^2\tau_i}{\tilde{\sigma}_x(i)\sqrt{\tau_i}},$$

so that

$$\frac{\partial e_i}{\partial\lambda} = -\frac{\sqrt{\tau_i}}{\tilde{\sigma}_x(i)}.$$

Let $\psi(e) \equiv \ln N(e)$. Then $\psi'(e) = n(e)/N(e)$ and

$$\psi''(e) = \frac{d}{de}\Big(\frac{n(e)}{N(e)}\Big) = -\frac{n(e)}{N(e)}\Big(e + \frac{n(e)}{N(e)}\Big).$$

Using the chain rule,

$$\begin{aligned}
\beta_i'(\lambda) &= -\frac{1}{\tilde{\sigma}_x(i)\sqrt{\tau_i}}\;\psi''\big(e_i(\lambda)\big)\;\frac{\partial e_i}{\partial\lambda} \\
&= -\frac{1}{\tilde{\sigma}_x(i)\sqrt{\tau_i}}\;\Big[-\frac{n}{N}\Big(e + \frac{n}{N}\Big)\Big]_{e=e_i(\lambda)}\;\Big(-\frac{\sqrt{\tau_i}}{\tilde{\sigma}_x(i)}\Big) \\
&= -\frac{1}{\tilde{\sigma}_x(i)^2}\;\frac{n(e_i(\lambda))}{N(e_i(\lambda))}\Big(e_i(\lambda) + \frac{n(e_i(\lambda))}{N(e_i(\lambda))}\Big).
\end{aligned} \tag{B18}$$

Since $\dfrac{n(e_i)}{N(e_i)} = -\beta_i(\lambda)\,\tilde{\sigma}_x(i)\sqrt{\tau_i}$, equation (B18) simplifies to

$$\beta_i'(\lambda) = \frac{\beta_i(\lambda)\sqrt{\tau_i}}{\tilde{\sigma}_x(i)}\,\big(e_i(\lambda) - \beta_i(\lambda)\,\tilde{\sigma}_x(i)\sqrt{\tau_i}\big)\,. \tag{B19}$$

Define the effective KPI feasibility:

$$m_i(\lambda) \equiv e_i(\lambda)\,\frac{\sqrt{\tau_i}}{\tilde{\sigma}_x(i)} = \frac{\ln(x_t(i)/K(i)) + \big(\tilde{\mu}_x(i) - \lambda(i)\big)\tau_i - \frac{1}{2}\tilde{\sigma}_x(i)^2\tau_i}{\tilde{\sigma}_x(i)^2}.$$

Evaluating (B17) at $\lambda = \lambda$ yields the compact expression:

$$\Gamma_i = \beta_i(\lambda) + \lambda\,\beta_i(\lambda)\,m_i(\lambda) - \lambda\,\beta_i(\lambda)^2\,\tau_i. \tag{B20}$$

Cross-sectional variation in Γ_i arises from dispersion in moneyness and KPI feasibility—through $\beta_i(\lambda)$, $\beta_i(\lambda)m_i$, and $\beta_i(\lambda)^2\tau_i$. In particular, the factor exposure $\beta_i(\lambda)$ tends to decrease with longer maturity τ_i. When this cross-sectional dispersion is limited,

$$\Gamma_i \approx \bar{\Gamma}, \qquad \text{and} \qquad \sum_i \tilde{\lambda}_i^2 \approx 0,$$

the total approximation error implied by the Taylor expansion in (B16) becomes negligible:

$$\sum_i \big(\Gamma_i\,\tilde{\lambda}_i + O(\tilde{\lambda}_i^2)\big) \approx \bar{\Gamma}\sum_i \tilde{\lambda}_i + O\Big(\sum_i \tilde{\lambda}_i^2\Big) \approx 0.$$

Therefore, under mild dispersion in KPI feasibility and firm-specific deviations $\tilde{\lambda}_i$, the aggregate premium $\sum_i \beta_{i,t}(\lambda(i))\lambda(i)$ is well approximated by the common quantity $\sum_i \beta_{i,t}(\lambda)\lambda$, validating the use of a single common λ in the main estimation.

Appendix C Estimation and Statistical Inference for λ

C1 Two-step Estimation

We adopt a two-step estimation framework to recover λ from the specification in (34). The procedure separates the linear and nonlinear components, improving tractability while ensuring consistent estimation.
Step 1: Estimating linear coefficients for a given λ. For any candidate value of λ, we estimate the fixed effects and linear coefficients by ordinary least squares (OLS) from the following regression:

$$L_i, D_{yr}, \mathbf{B}, w = \arg\min \frac{1}{I\cdot T}\sum_{i=1}^{I}\sum_{t=1}^{T}\Big(R_{i,t+1}^{SLB} - \big[L_i + D_{yr} + w\,\beta_{i,t}(\lambda)\big(\lambda + g_{i,t+1}\big) + (1-w)R_{i,t+1}^{NSLB} + \mathbf{B}^\top\mathbf{X}\big]\Big)^2. \tag{C1}$$

Here, I and T denote the number of SLBs and the sample length in the panel data, respectively. This step yields the estimated linear coefficients $\mathbf{B}(\lambda)$ and $w(\lambda)$, along with the fixed effects $L_i(\lambda)$ and $D_{yr}(\lambda)$, each conditional on the candidate value of λ.
Step 2: Estimating the nonlinear parameter λ. Given the fitted coefficients from Step 1, we estimate λ by minimizing the mean squared error across all SLBs and time periods:

$$\lambda = \arg\min \frac{1}{I\cdot T}\sum_{i=1}^{I}\sum_{t=1}^{T}\Big(R_{i,t+1}^{SLB} - \big[L_i(\lambda) + D_{yr}(\lambda) + w(\lambda)\beta_{i,t}(\lambda)\big(\lambda + g_{i,t+1}\big) + (1-w(\lambda))R_{i,t+1}^{NSLB} + \mathbf{B}(\lambda)^\top\mathbf{X}\big]\Big)^2. \tag{C2}$$

Intuitively, the first step linearly projects SLB returns on their sustainability-linked exposure, benchmark bond returns, and other controls for any given λ. The second step then determines the value of λ that minimizes the overall fitting error. This two-step framework efficiently separates the nonlinear dependence on λ through $\beta_{i,t}(\lambda)$ and allows OLS-based estimation of all other parameters.

C2 Asymptotic Inference

In general, an extremum estimator such as our sustainability risk premium $\hat{\lambda}$ is asymptotically normal with a covariance matrix that follows the standard *sandwich form* (Newey and McFadden, 1994). The loss function on the parameter of interest λ is

$$L(\lambda) = \frac{1}{I \cdot T} \sum_{i=1}^{I} \sum_{t=1}^{T} \left(R_{i,t+1}^{SLB} - L_i - D_{yr} - (1-w) R_{i,t+1}^{NSLB} - w\, \beta_{i,t}(\lambda)\, (\lambda + g_{i,t+1}) - \mathbf{B}^{\top}\mathbf{X} \right)^2 . \tag{C3}$$

After absorbing fixed effects, this loss function can be rewritten as a single-dimensional mean squared error:

$$L(\lambda) = \frac{1}{N} \sum_{n=1}^{N} \mathrm{err}_n^2, \tag{C4}$$

where $N = I \cdot T$ is the total number of observations, and err_n is the fitted residual of each SLB at each time point.

Under standard regularity conditions, the estimator is asymptotically normal:

$$\sqrt{N}\,(\hat{\lambda} - \lambda) \xrightarrow{d} \mathcal{N}(0, V), \quad V = H^{-1} S\, H^{-1},$$

where $H = E[\nabla^2 L(\lambda)]$ is the expected Hessian of the loss function and $S = \mathrm{Var}(\nabla L(\lambda))$ is the variance of the score (gradient) function.

We compute the sandwich estimator as $\hat{V} = \hat{H}^{-1} \hat{S}\, \hat{H}^{-1}$, where both $\hat{H}$ and $\hat{S}$ are sample analogues. Specifically, $\hat{H}$ is the sample mean of the numerical second derivatives (Hessian) of the loss function with respect to λ, while $\hat{S}$ is the sample variance of the first derivatives (gradients):

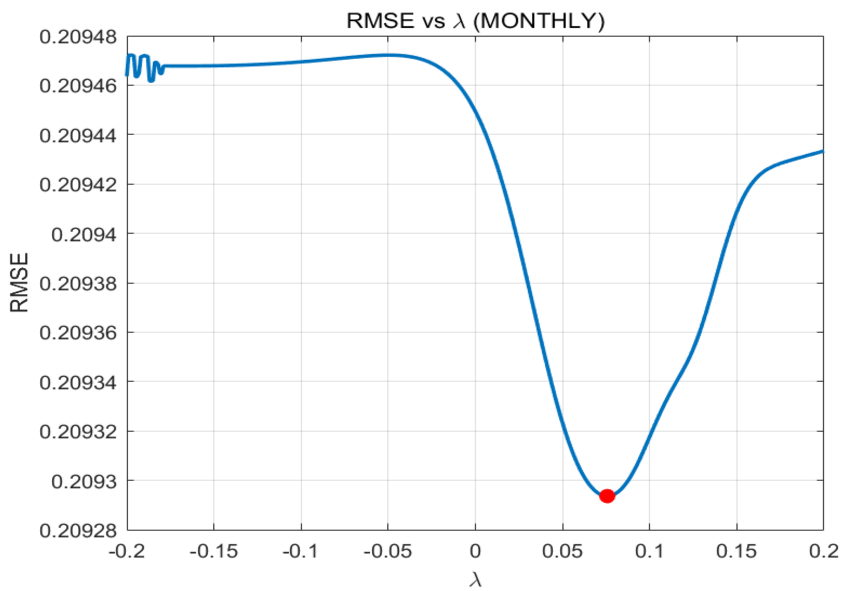
$$\hat{S} = \frac{1}{N} \sum_{n=1}^{N} (\nabla_{\lambda} \mathrm{err}_n)^2.$$

Because gradients may be correlated across time or across SLBs within the same country, we cluster the computation of $\hat{S}$ by *country*. This clustered version of $\hat{S}$ aggregates gradients within each cluster before forming the variance, thus providing heteroskedasticity- and autocorrelation-robust standard errors that account for within-country dependence.

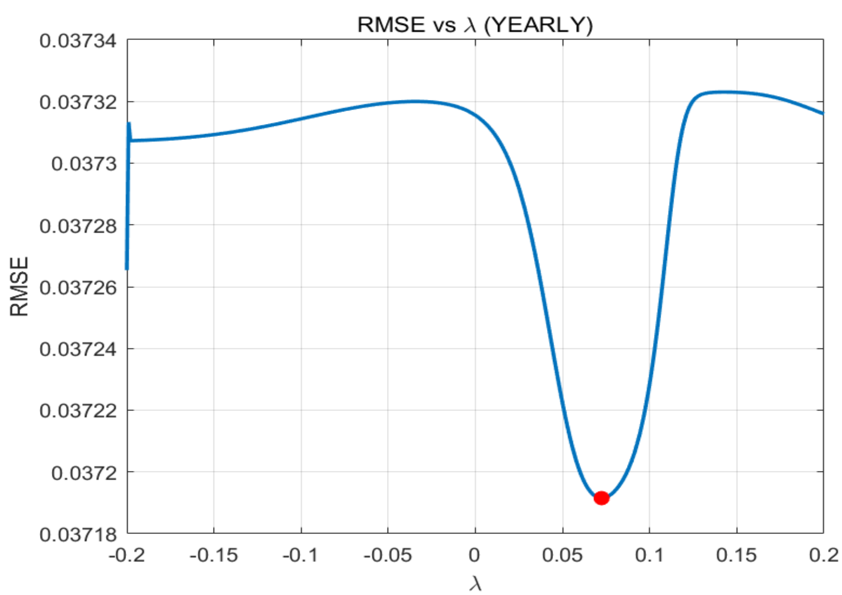
As a robustness check, we also evaluate alternative clustering schemes and report the T-statistics in Table C.1, including clustering by *industry, pair of country-industry, year*, and we confirm that the inference results remain qualitatively unchanged. In addition, we verify that assuming the gradients are i.i.d. across time and individual bonds yields nearly identical estimates of the asymptotic variance, confirming that our inference is not sensitive to the clustering choice.

Figure C.1 further illustrates the effectiveness of this non-linear mean-squared estimation at monthly and yearly frequencies. In both specifications, the RMSE drops sharply at the optimal λ estimate, consistent with the intuition from the sandwich-formatted variance estimator that the second-order derivative is large at the optimum.

Additional Figures and Tables



(A)



(B)

Figure C.1: RMSE of Equation Equation 34 with Different λs

This figure plots the relationship between λ and the root mean square error (RMSE) of equation Equation 34 using both monthly and yearly frequency. The monthly regression includes SLB and year fixed effects, while the yearly regression includes country, industry and year fixed effects.

TABLE C.1: Robustness of λ under Alternative Clustering Schemes

This table reports the robustness of the estimated sustainability risk premium λ to alternative clustering schemes for standard errors. Panel A presents the monthly estimation with SLB and year fixed effects. Panel B reports the yearly estimation with industry, country, and year fixed effects. For each specification, we report the point estimate of λ and t-statistics based on: country clusters (*T(Ctry)*), industry clusters (*T(Ind)*), two-way industry–country clusters (*T(Ind,Ctry)*), year clusters (*T(Year)*), and no clustering (*T(No Cluster)*). Columns correspond to the full sample (*All*), European issuers (*EU*), Industrial-sector SLBs, SLBs with raw-emission KPIs, SLBs with ESG-score KPIs, and non-callable SLBs. Blank cells indicate that the corresponding statistics are not applicable for that panel.

	All	EU	Industrial	Raw Emission	ESG Score	Non-Callable
Panel A: Monthly Estimation (FEs: SLB, Year)						
λ	0.076	0.080	0.078	0.115	0.048	0.067
T(Ctry)	6.958	7.182	7.110	2.588	10.353	4.178
T(Ind)	9.971	9.532		14.830	19.187	9.562
T(Ind,Ctry)	9.641	8.946		16.616	15.562	7.285
T(Year)	4.158	6.280	4.276	2.253	41.162	12.683
T(No Cluster)	4.145	5.907	4.876	1.955	6.826	3.194
Panel B: Yearly Estimation (FEs: Industry, Country, Year)						
λ	0.072	0.094	0.071			
T(Ctry)	2.566	3.347	4.669			
T(Ind)	3.645	3.937				
T(Ind,Ctry)	3.558	3.771				
T(Year)	6.350	13.126	8.314			
T(No Cluster)	2.835	4.339	4.878			