Journal of Financial Economics 162 (2024) 103944

Contents lists available at ScienceDirect

Journal of Financial Economics

journal homepage: www.elsevier.com/locate/finec

Pricing of sustainability-linked bonds[☆]

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ARTICLE INFO

Dataset link: Pricing of Sustainability-Linked Bonds Dataset (Reference data)

JEL classification:
G12

Keywords:
ESG
Sustainability-linked bond
Corporate bonds
Step-up coupon
Sustainium

ABSTRACT

We examine the pricing of sustainability-linked bonds (SLBs), where the cash flows depend on the bond issuer achieving one or more Environmental, Social and Governance (ESG) goals. Investors are willing to accept a 1–2bps lower yield due to the bond's ESG label, providing evidence of investors caring about environmental impact. Furthermore, we find the average probability of missing the target is 14%–39% so firms set ESG targets that are easy to reach. We find that the SLB market is efficient: the prices of SLBs depend strongly on the size of the potential penalty and there is no evidence of mispricing. Finally, our results suggest that SLBs serve as financial hedges against ESG risk.

1. Introduction

Sustainability has become a central concern for governments, corporations, regulators and investors. A number of financial securities, particularly debt instruments, designed to align financial incentives with ESG objectives have come to existence in the past decade. For example, sustainable bonds where revenues from the bond issue are limited to funding ESG investments, have grown tremendously in recent years. Critics argue that companies have no direct financial incentive to act ESG-friendly once such bonds are issued. As a potential solution to this incentive problem, firms have recently begun to issue sustainability-linked bonds (SLBs). In contrast to sustainable bonds there are no limitations on how the proceeds are used, but bond cash flows are tied to the company achieving future ESG goals. In a typical SLB structure, the firm commits to a future carbon reduction target, and if the target is not met, the bond's coupon increases. Compared to standard sustainable bonds, SLBs may be more effective at directing companies to contribute to a sustainable economy. However, if firms choose easy targets or SLBs are mispriced as Kölbel and Lambillon (2023) find, SLBs will not work as intended.

In this paper, we extensively examine the pricing of SLB. We calculate the SLB price premium as the price difference between an SLB and a synthetic identical ordinary bond with no ESG label and find (1) investors are willing to pay a premium for the ESG label itself, (2) there is a strong relation between the SLB price premium and the penalty size for missing the target, (3) the average SLB price premium is less than the sum of penalties, i.e. "no arbitrage", (4) the average probability of meeting the target is high at 61%–86%, and (5) evidence that SLBs serve as hedges against ESG risk.

We calculate the SLB price premium as the price difference between the SLB and an ordinary bond. To take into account differences in coupon rates between the SLB and ordinary bonds, we start by calculating an SLB yield premium and then convert it to an SLB price premium. The SLB yield premium is calculated in the secondary market as the difference in yield spread between an ordinary non-labelled bond and an SLB, both issued by the same firm. Specifically, on a daily basis, we match each SLB with two non-labelled bonds that have a longer and shorter maturity and interpolate the non-labelled bonds' yield spreads to generate a non-SLB synthetic yield spread with the same maturity as the SLB. The difference between the synthetic yield spread and the

☆ We thank Dimitris Papanikolaou who was the editor for this article and an anonymous referee for very useful comments. We are also grateful for valuable comments and suggestions received from Jens Dick-Nielsen, Thomas Geelen, Lena Jaroszek, David Lando, Lasse Heje Pedersen and seminar participants at Copenhagen Business School. Peter Feldhütter gratefully acknowledges support from the Danish Finance Institute (DFI) and the Center for Big Data in Finance (Grant no. DNRF167).

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https://doi.org/10.1016/j.jfineco.2024.103944
Received 13 September 2023; Received in revised form 6 September 2024; Accepted 6 September 2024
Available online 12 September 2024

SLB yield spread is the SLB yield premium. We convert the SLB yield premium to an SLB price premium,

SLB price premium = SLB bond price - ordinary bond price,

using our pricing model.

We first investigate if investors are willing to pay a markup for the ESG label itself. Evidence from the literature on green bonds has established that investors are willing to pay a markup for a green bond label (Zerbib, 2019; Caramichael and Rapp, 2024; Feldhütter and Pedersen, 2024 and others), implying that ESG investors accrue non-pecuniary benefits through indirect ownership of green assets (Bonnefon et al., 2022). Since SLBs are not tied to specific assets, a green bond markup does not imply an SLB markup. If the impact of investment decisions is important for investors (Moisson, 2022), however, they would pay a premium for SLBs because the bonds incentivize firms to take ESG-friendly actions. Testing if investors are willing to pay a markup for the ESG label of SLBs on its own is difficult since one would need to separate the value of potential additional cash flows to bondholders from the value of the ESG label itself. To circumvent this difficulty, we use a subset of SLBs that have a penalty defined in terms of donations or carbon offset. These bonds are ideal for studying the value of the ESG label, because there are no potential additional payments to bond holders and therefore the SLB premium must be due to the ESG label itself. We find a positive but modest SLB yield premium of 1.9 bps – which we call the sustainium – for this subset of SLBs providing empirical support for the importance of impact investing.

Turning next to our main sample of SLBs where investors do receive additional cash flows if the firm fails to reach the ESG target(s), we investigate the size and determinants of the SLB price premium. We find that the SLB price premium is strongly positively related to the penalty size — the sum of penalty cash flows in case the firm fails to reach the ESG target(s). This result indicates that, as basic financial theory predicts, the market accounts for the size of optional cash flows. Surprisingly, Kölbel and Lambillon (2023) report that the SLB premium is larger than the sum of penalties. This may be the case if investors misprice cash flows or are willing to pay a sufficiently large sustainium. If so, firms can engage in greenwashing by issuing overpriced SLBs with no intention of reaching the ESG target(s). We find that the average SLB premium is significantly less than the sum of penalties and, thus, our results suggest no evidence of such greenwashing potential in the market.

Investors and regulators voice concerns that targets "lack ambition and are too easy to meet",[1] which is why the International Capital Market Association recommends that targets are ambitious and "beyond a Business as Usual trajectory" (ICMA, 2020). In a survey of professional investors in 2021, investors' main concern regarding SLBs is the "risk of greenwashing".[2] If correct, firms can engage in greenwashing behaviour by issuing SLBs with targets that are easy to reach and then earn the sustainium. We investigate whether these concerns are warranted by estimating the probability of firms missing their ESG target(s). To do so, we exploit that many SLB issuers follow the International Capital Market Association's guidance and publish historical values of Key Performance Indicators (KPIs) on which the targets are based. We assume that the KPI follows a generalized Wiener process, calibrate the parameters to historical values and use the parameters to calculate the probability that the future target will be missed. We calculate the probability under different scenarios and we find that the average probability of missing the target is only 14%–39%, depending on assumptions. Even under the most relaxed assumption about the firm's commitment, that the future commitment is the same as the historical commitment, the probability of missing the target is only 39%. This suggests that targets are indeed too soft and business-as-usual, interpreting business-as-usual as continuing a historical trajectory in the future.

Finally, we estimate the risk premium associated with ESG risk for the SLBs with ESG-linked cash flows. To do so, we first regress the yield sustainium on firm characteristics for the subset of SLBs with no ESG-linked cash flows, and use the regression coefficients to estimate the yield sustainium for the larger sample. Then, we use the estimated yield sustainium to calculate the price of a synthetic SLB bond – sustainium-only price – with the same maturity and coupon, but without ESG-linked cash flows. We compute the price of the optional ESG cash flows as

ESG cash flow price = SLB bond price - sustainium-only bond price,

and use the estimates of probabilities of missing the target in conjunction with our pricing model to compute the expected present value of the optional ESG cash flows, $\mathrm{E}\big[\text{ESG cash flows}\big]$. The ESG risk premium is then

$$\text{ESG risk premium} = \mathrm{E}\Big[\text{ESG cash flows}\Big] - \text{ESG cash flow price}.$$

There is no consensus on the sign of the ESG risk premium, and for the most common targets related to greenhouse gas (GHG) emissions, there are arguments for both a positive and negative risk premium.[3] The risk premium would be positive if, when the economy experiences a positive growth shock, output and GHG emissions increase (Nordhaus, 1977). In these states of high consumption, firms are more likely to miss their ESG targets and SLBs pay out additional cash flows. The risk premium would be negative if global warming, caused by GHG emissions, results in higher risk of climate disasters leading to a negative macro-economic shock (Bansel et al., 2019). In such a scenario, SLBs act as a hedge against climate risk, since firms have not reduced GHGs and SLBs pay out extra cash flows.

We find that the average risk premium is negative and statistically significant in most specifications, providing evidence that SLBs serve as financial hedges against ESG risk. However, the evidence for a negative risk premium is weak for SLBs where targets are tied to GHC emissions, suggesting that the negative risk premium is not driven by a negative climate change risk premium.

The theoretical model uses the intensity-based method proposed by Lando (1998) and Duffie and Singleton (1999). There is a stochastic riskfree interest rate, the firm defaults with a stochastic default intensity and, in case of default, bondholders receive a stochastic recovery rate. Investors may have a stochastic convenience of holding an SLB, which we denote the sustainium. The firm sets one or more future ESG targets and for each target there is an incremental set of future cash flows bondholders receive if the target is not met. We derive the bond price and provide closed-form solutions in the case of a constant interest rate, default intensity, sustainium and recovery rate.

Our work is most closely related to Kölbel and Lambillon (2023) who compare the SLB yield at issuance with the issuance yield of a non-SLBs from the same issuer issued no more than five years apart. We refine their approach as we match the secondary market SLB yield spread with an interpolated yield spread from non-SLB bonds from the same issuer on the same day. Thus, while we compare SLB and non-SLB yield spreads from the same issuer on the same day, Kölbel and Lambillon (2023) compare SLB issuance yields with yields of ordinary bonds that are on average issued 1 1/2 years earlier and changes in riskfree rates, macro variables, and issuer-specific credit risk introduce noise in their results. Furthermore, in contrast to their paper, we estimate a model, estimate the sustainium, the probability of hitting the target and investigate ESG risk premiums. We focus on pricing

[1] See for example Reuters, November 9, 2022, "Explainer: Decoding COP27: the many shades of green bonds" (https://www.reuters.com/business/cop/decoding-cop27-many-shades-green-bonds-2022-11-09/.

[2] https://gsh.cib.natixis.com/api-website-feature/files/download/11818/SLB-Survey-Short-Results_2021-03-FinalVersion_LAST.pdf.

[3] See Giglio et al. (2021) for an extensive review.

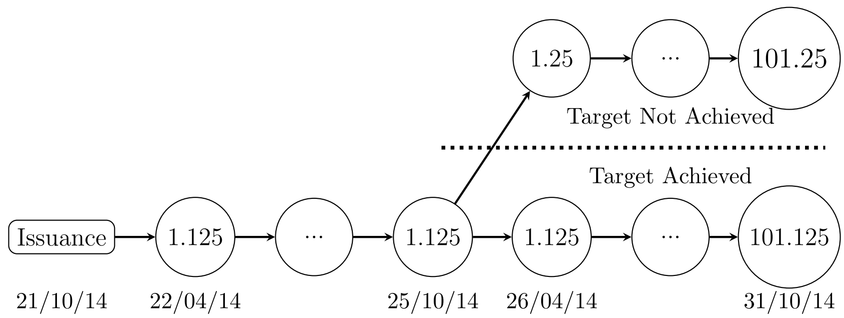

Fig. 1. *SLB issued by General Mills in 2021.* This figure illustrates the possible cash flows of the SLB issued by General Mills on October 14, 2021. The bond has a fixed semi-annual coupon of 1.125% and if General Mills fails to achieve a target reduction of 21% in scope 1 and scope 2 greenhouse gas emissions by 2025, the semi-annual coupon increases by 0.125%.

SLBs in this paper and do not study the optimal design of SLBs. Our anecdotal evidence indicates that the size of penalties relative to overall interest expenses is low, making it unlikely that the value of the ESG-related penalties in itself have a material impact on firms' transition to a greener economy, and Berrada et al. (2022) provide a theoretical framework for understanding the relation between firm effort and size of penalties. Erlandsson and Mielnik (2022) provide a pricing model for SLBs and calibrate it to two bonds at issuance while we have an extensive sample of SLB bonds over a longer period.[4]

The structure of the paper is the following. In Section 2 we provide an overview of the market for SLBs. Section 3 describes the model and estimation approach, while Section 4 details the data. Section 5 describes the empirical results and Section 6 concludes.

2. Sustainability-linked bonds

A variety of new debt securities have been introduced in recent years to aid firms make the transition to a greener and more socially responsible economy. For instance, the proceeds from green bonds are restricted to green projects, the proceeds from blue bonds are used for investments in healthy oceans, while funds raised from social bonds are used for projects that have a positive impact on society. Such debt securities do not impose any limitations on the company's future behaviour once the underlying projects have been funded. Sustainability-linked bonds (SLBs), a more recent innovation that was introduced in 2018, are fundamentally different from other ESG-related securities. SLBs directly link the cash flows of the bond to one or several ESG-related Key Performance Indicators (KPIs) rather than placing restrictions on how bond proceeds are used. This implies that the firm have financial incentives to act in an ESG-friendly manner after the bonds are issued.

For the purpose of illustration, consider a typical SLB: a 10-year bond issued by General Mills on October 14, 2021, with a fixed coupon rate of 2.25% and semi-annual payments. General Mills' annual coupon rate will increase by 25 basis points starting on April 14, 2026, if it is unable to reduce scope 1 and scope 2 greenhouse gas emissions by 21 percent by the target date May 25, 2025, in comparison to a benchmark for 2020. The cash flows of the bond is illustrated in Fig. 1.

To assess how large the penalty is relative to the size of General Mills, we note that the offering amount of the SLB is $500 mio, so the annual penalty amounts to $1.25 mio. Additionally, General Mills had a sustainability-linked loan with a notional amount of $1000 mio and a maximum penalty of 10 bps. Overall, this implies a penalty of $2.25 mio if General Mills miss both targets. For comparison, the firm's interest expenses in 2021 was $430.9 mio according to their annual report, so missing sustainable-linked targets would only increase their interest rate expenses by 0.52%. The firm may issue more SLBs with higher penalties in the future as the market matures, but the current penalties are too small to affect the firm in a material way.

Table 1
General Mill's greenhouse gas emissions. Historical data for scope 1 and scope 2 greenhouse gas emissions by General Mills, provided in the second party opinion by Institutional Shareholder Services Inc ahead of General Mill's issue of a 10-year SLB on October 2021.

	2018	2019	2020	2025 (Target)
GHG scope 1 and 2 emissions (million metric tons of CO2e)	0.88	0.71	0.75	0.59
YoY reduction (%)		−19.32	5.63	

A recent example of triggered SLB penalties is Enel. The Italian energy company triggered a penalty of 25 bps on ten SLBs on April 23, 2024 by missing its greenhouse-gas emissions targets (Fitch, 2024). The penalties imply an additional interest expense of EUR 25 mio ($26.8 mio) amounting to 0.44% of Enel's overall interest expenses (according to their 2023 annual report), suggesting that the SLB market has not yet matured to an extent that penalties have a sizeable impact on total interest expenses.

It is advised by the International Capital Market Association that firms publish at least three years of historical values of their target KPIs and the historical greenhouse gas emissions of General Mills are shown in Table 1. General Mills must reduce emissions by 32.9% in 2025 compared to 2018. A reduction of 19.3% was made in 2019 alone, but this was followed by an increase of 5.6% in 2020.

The development of the SLB market is depicted in Fig. 2. Both the number and notional amount issued have dramatically increased, as shown in Panel A. Between 2018 and March, 2024, 722 SLBs have been issued. The total notional amount issued for the 722 SLBs is 273 USD billions. Panel B shows that half of the bonds were issued in Europe, followed by 33 percent in Asia and 12 percent in North America.

Different KPIs, KPI targets, penalty types, and penalty sizes are used to structure SLBs as Table 2 shows. The most common KPI measures greenhouse gas emissions (GHG), intended to lower scope 1, 2, or 3 greenhouse gas emissions for the entire company or a particular segment of the firm's operations. The second-most popular group of KPIs is related to renewable energy, such as an increase in the portfolio of renewable energy assets for energy companies or a greater reliance on renewable energy for non-energy firms. A significant number of KPIs are concerned with maintaining or raising a company's ESG rating. Finally, some KPIs are related to diversity, typically the proportion of minority groups to the majority. For instance, on September 13, 2021 Suzano Austria GmbH issued an SLB with one of the KPI targets being to reach a level of at least 30% women in leadership roles by

[4] More broadly, there is a growing literature on green bonds including Zerbib (2019), Baker et al. (2022), Caramichael and Rapp (2024), Flammer (2021), and Larcker and Watts (2020). Pedersen et al. (2021), Pastor et al. (2021) and Feldhütter and Pedersen (2024) investigate pricing in presence of ESG investors and Engle et al. (2020), Ilhan et al. (2021), Huynh and Xia (2021), Seltzer et al. (2022), Bolton and Kacperczyk (2021, 2023), Oehmke and Opp (2024) and Avramov et al. (2022) look at the pricing of ESG risk.

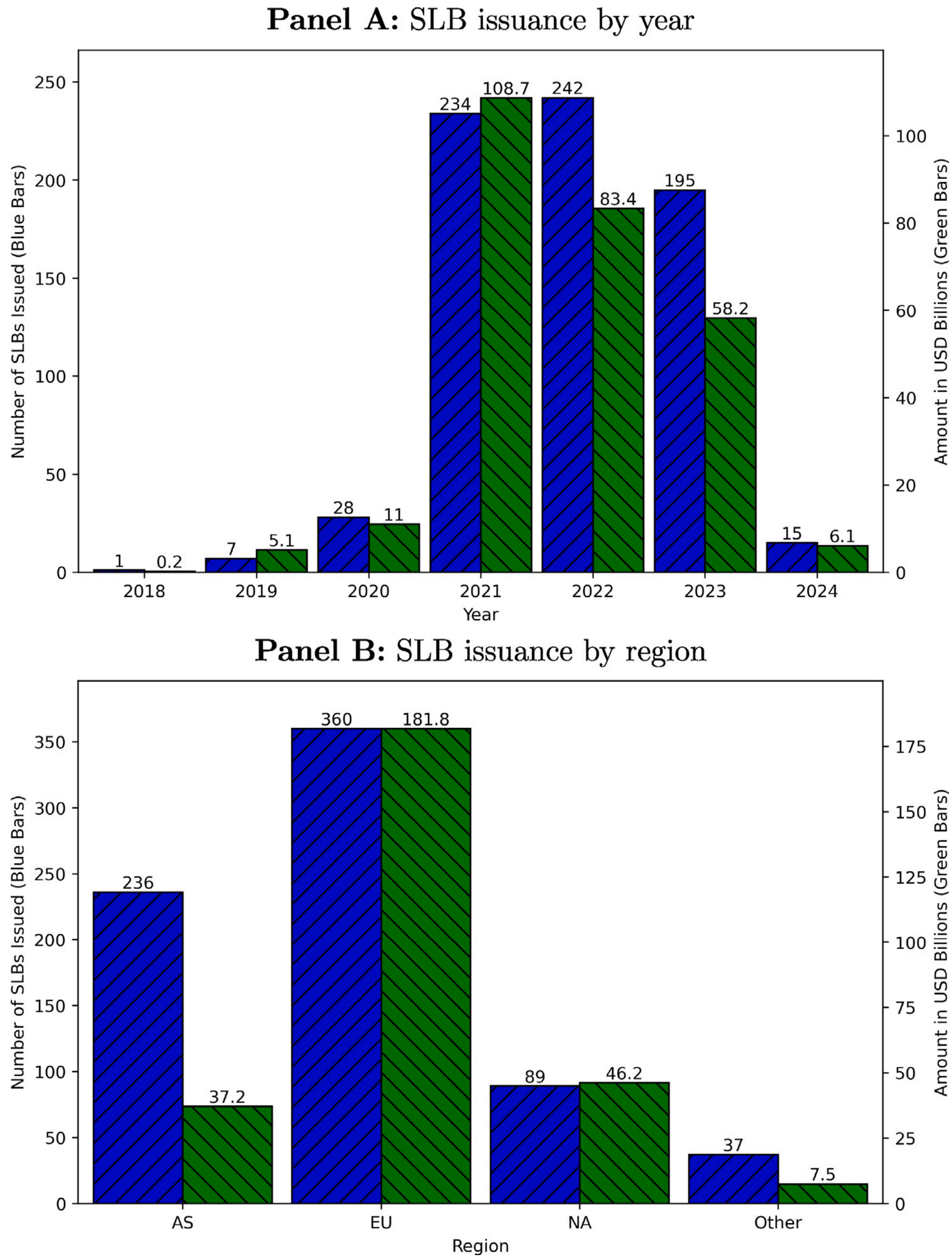

Fig. 2. This figure shows the growth of the SLB market since its inception in 2018. The left (blue) bars show the number of SLBs issued each year while the right (green) bars show the notional amount of SLBs issued (in USD billions). The data is from Bloomberg and includes all bonds that have a sustainability-linked indicator equal to 1. The data for 2024 ends March 4. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2025. "Other" KPIs includes metrics that are company-specific, such as decreased food and water waste for food and beverage companies or the building of affordable housing for construction companies.

Table 2 Panel B lists type of penalties and we see that most SLBs are accompanied by a coupon step up, i.e. an increase in the bond's coupon. Some bonds have a coupon step-down reducing the coupon if the company achieves the target. Pure step-downs are uncommon, whereas coupon step up/down, where the coupon rate can change based on the KPI's performance at the target observation date, are more frequent (a common structure is to let the coupon depend on the firm's ESG rating). A cash/redemption penalty implies that the company pays a one-time cash premium or increases the bond's redemption price. There are 62 bonds where the penalty is to donate money to a charity or buy carbon offset certificates. The distribution of the size of the penalty for targets with a step-up feature is displayed in Panel C. Out of 427 SLBs with a coupon step up, 220 (52%) have a 25 bps coupon increase, 120 (28%) have less than a 25 bps increase, and 76 (18%) have more than a 25 bps increase.

3. A model for sustainability-linked bonds

In Section 3.1 we derive a model for pricing SLBs using the default-intensity method proposed by Lando (1998) and Duffie and Singleton (1999). We derive the model with multiple ESG targets, a stochastic interest rate, default intensity, recovery rate, and a premium for

Table 2
Structure of SLBs. Panel A shows types of KPIs, Panel B types of penalties and Panel C the distribution of penalty size for SLBs that have a coupon step up penalty. In Panel A 268 SLBs have multiple KPIs and can thus enter into multiple rows of the panel. The KPI information is manually collected using a combination of Bloomberg notes, bond prospectuses, company websites, and second party opinions. The data period is December, 2018 to March, 2024.

Panel A: KPI type		
	# of SLBs issued	Issuance amount (USD Billions)
GHG (Greenhouse Gas)	410	195.4
Other	233	72.0
Renewables	125	37.6
ESG rating	65	16.8
Diversity	38	16.5
Missing Info	36	8.2
Multiple KPIs	268	108.2
Panel B: Penalty type		
	# of SLBs issued	Issuance amount (USD Billions)
Coupon step up	427	198.3
Cash/Redemption	86	29.1
Coupon step up/Down	68	16.9
Carbon offset/Donation	62	11.3
Missing info	36	7.9
Complex	33	7.7
Coupon step down	8	0.5
Panel C: Coupon step up penalty		
	# of SLBs issued	Issuance amount (USD Billions)
=25 BPS	220	131.8
<25 BPS	120	26.0
>25 BPS	76	39.5
Missing info	11	1

sustainability. In Section 3.2 we simplify the model by assuming constant values for the interest rate, default frequency, recovery, and sustainability premium, and detail how we estimate the model.

3.1. A general model

The bond has promised cash flows $C_1, \dots, C_M$ at times $t_1^C, \dots, t_M^C$ and without loss of generality we assume that we are pricing the bond at time 0. The firm has K ESG factors $G_t^j, j = 1, \dots, K$ and if factor j is above some target at time T_j, K_j, bond investors receive additional positive cash flows $S_1^j, \dots, S_{N_j}^j$ at times $t_1^j, \dots, t_{N_j}^j$, where $T_j \le t_i^j \le t_M^C, i = 1, \dots, N_J$.

We consider a low ESG factor to be favourable in an ESG sense. For instance, if the ESG factor is carbon emissions, a firm that has not sufficiently reduced its carbon emissions will be penalized by having to pay additional coupons if the factor is above the target. A high ESG factor is positive in some cases, for instance when the goal is to reach a certain percentage of female employees. In this case we look at $-G_t$ and the condition is then $-G_t > -K$. Some bonds (although none in our empirical sample) have a step-down coupon structure, such that the coupons are reduced if the firm reaches the ESG target. In this case we think of the cash flows $C_1, \dots, C_M$ as the cash flows in case the firm reaches the ESG target and additional cash flows $S_1^j, \dots, S_{N_j}^j$ as the negative value of the step-down coupons.

Independent of the cash flows, investors may have a convenience of holding the bond, the sustainability premium or "sustainium", which we denote ω_t.

Let λ_t be the default intensity for the bond-issuing firm and r_t the riskfree rate. If the firm defaults at time τ bondholders receive δ_τ. We can think of the investor as selling the bond at default in which case δ_τ is the trading price of the bond. The value of bond cash flows is (see Lando (1998) and Duffie and Singleton (1999)):

$$P_0^{SLB} = E_0^Q\Big[\sum_{i=1}^{M} C_i e^{-\int_0^{t_i^C}(r_s+\lambda_s-\omega_s)ds}\Big]$$

$$+ \sum_{j=1}^{K} E_0^Q\Big[1_{\{G_{T_j}^j > K_j\}} \sum_{i=1}^{N_j} S_i^j e^{-\int_0^{t_i^j}(r_s+\lambda_s)ds}\Big] \quad (1)$$

$$+E_0^Q\Big[\int_0^{t_M^C} \delta_u \lambda_u e^{-\int_0^u (r_s+\lambda_s-\omega_s)ds} du\Big] \quad (2)$$

$$= \sum_{i=1}^{M} C_i D(r_0, \lambda_0, \omega_0, t_i^C) + \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j F(r_0, \lambda_0, G_0^j, K_j, t_i^j, T_j) \quad (3)$$

$$+ R(r_0, \lambda_0, \omega_0, \delta_0, t_M^C), \quad (4)$$

where

$$D(r_0, \lambda_0, \omega_0, t) = E_0^Q\Big[e^{-\int_0^t (r_s+\lambda_s-\omega_s)ds}\Big], \quad (5)$$

$$F(r_0, \lambda_0, G_0, K, t, T) = E_0^Q\Big[1_{\{G_T > K\}} e^{-\int_0^t (r_s+\lambda_s)ds}\Big], \quad (6)$$

$$R(r_0, \lambda_0, \omega_0, \delta_0, t) = E_0^Q\Big[\int_0^t \delta_u \lambda_u e^{-\int_0^u (r_s+\lambda_s-\omega_s)ds} du\Big]. \quad (7)$$

Note that the model takes into account that ESG-investors value penalty cash flows less than the other bond cash flows since the sustainium is not included when discounting potential penalties in the last term in Eq. (1). We decompose the price of the SLB into a standard bond component and an option:

$$P_0^{SLB} = P_0^{SUS} + O_0, \quad (8)$$

$$P_0^{SUS} = \sum_{i=1}^{M} C_i D(r_0, \lambda_0, \omega_0, t_i^C) + R(r_0, \lambda_0, \omega_0, \delta_0, t_M^C), \quad (9)$$

$$O_0 = \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j F(r_0, \lambda_0, G_0, K_j, t_i^j, T_j), \quad (10)$$

where P_0^{SUS} is the price of a "sustainium bond" without any option-linked cash flows and O_0 is the value of the option-linked cash flows. The price of an ordinary (non-ESG) bond with no option features is

$$P_0^o = \sum_{i=1}^{M} C_i D'(r_0, \lambda_0, t_i^C) + R'(r_0, \lambda_0, \delta_0, t_M^C) \quad (11)$$

where

$$D'(r_0, \lambda_0, t) = E_0^Q\Big[e^{-\int_0^t (r_s+\lambda_s)ds}\Big], \quad (12)$$

$$R'(r_0, \lambda_0, \delta_0, t) = E_0^Q\Big[\int_0^t \delta_u \lambda_u e^{-\int_0^u (r_s+\lambda_s)ds} du\Big]. \quad (13)$$

The lower bound of the option price is zero, $O_0^{LB} = 0$, while the upper bound is given by

$$O_0^{UB} = \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j. \quad (14)$$

If the ESG factor(s) G are independent of the risk free rate r and the default intensity λ, Eq. (6) reduces to

$$F(r_0, \lambda_0, G_0, K, t, T) = E_0^Q\Big[1_{\{G_T > K\}}\Big] D'(r_0, \lambda_0, t), \quad (15)$$

and the required dollar compensation for ESG-related cash flow risk – the ESG premium – is

$$ESGP_0 = \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_0^P\Big[1_{\{G_{T_j} > K\}}\Big] D'(r_0, \lambda_0, t_i^j) - O_0 \quad (16)$$

$$= \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_0^P\Big[1_{\{G_{T_j} > K\}}\Big] D'(r_0, \lambda_0, t_i^j) \quad (17)$$

$$- \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_0^Q\Big[1_{\{G_{T_j} > K\}}\Big] D'(r_0, \lambda_0, t_i^j) \quad (18)$$

$$= \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j \Big(E_0^P\Big[1_{\{G_{T_j} > K\}}\Big] - E_0^Q\Big[1_{\{G_{T_j} > K\}}\Big]\Big) D'(r_0, \lambda_0, t_i^j). \quad (19)$$

3.2. A tractable model: Formulas and estimation

We now assume that the recovery rate, default intensity, sustainability premium, and riskfree rate are constant and estimate the model using a three-step procedure. For a given bond-day, as Section 3.2.1 details, we first estimate the price of a synthetic ordinary non-ESG bond with the same fixed cash flows as the SLB bond but with no option features and no sustainium. Then, we estimate the price of a bond with a sustainability premium but no option-linked cash flows as outlined in Section 3.2.2 and finally we estimate the ESG risk premium as Section 3.2.3 explains.

3.2.1. Ordinary bond and estimation of λ

The price of an ordinary (non-ESG) bond with no option features, given in Eqs. (11)–(13) simplifies to

$$P_0^o = \sum_{i=1}^{M} C_i D'(r,\lambda,t_i^C) + R'(r,\lambda,\delta,t_M^C) \tag{20}$$

$$D'(r,\lambda,t) = e^{-(r+\lambda)t}, \tag{21}$$

$$R'(r,\lambda,\delta,t) = \frac{\delta\lambda}{r+\lambda}\left(1-e^{-(r+\lambda)t}\right). \tag{22}$$

To estimate the price of an ordinary bond, we first compute the yield spread $s_{j,t}^o$ of an ordinary synthetic bond at time t with the same time-to-maturity as that of SLB j, $T_{j,t}$, by interpolating the yield spread of two ordinary bonds, one with a shorter maturity $T_{S,t}$ and one with a longer maturity $T_{L,t}$,

$$s_{j,t}^o = \frac{T_{L,t}-T_{j,t}}{T_{L,t}-T_{S,t}} * s_{S,t} + \frac{T_{j,t}-T_{S,t}}{T_{L,t}-T_{S,t}} * s_{L,t}, \tag{23}$$

where $s_{S,t}$ ($s_{L,t}$) is the yield spread of the short (long) maturity bond. If there is not a shorter and longer maturity bond, but two bonds with either shorter or longer maturity we extrapolate the yield spread. For example, if there are two ordinary bonds with a maturity of $T_{2,t} > T_{1,t} > T_{j,t}$, the yield spread of the ordinary bond is

$$s_{j,t}^o = \frac{T_{2,t}-T_{j,t}}{T_{2,t}-T_{1,t}} * s_{1,t} + \frac{T_{j,t}-T_{1,t}}{T_{2,t}-T_{1,t}} * s_{2,t}. \tag{24}$$

The yield-to-maturity of the ordinary bond is $y_{j,t}^o = s_{j,t}^o + r_{t,T_{j,t}}$ where $r_{t,T_{j,t}}$ is the $T_{j,t}-t$-year riskfree rate at time t.[5] We convert the discretely-compounded yield-to-maturity to a continuously-compounded yield-to-maturity $y_{j,t}^{o,cc}$ using the formula $y_{j,t}^{o,cc} = f_j * \ln(1+\frac{y_{j,t}^o}{f_j})$, where f_j is the coupon frequency for bond j. The price of the ordinary synthetic bond is then

$$\hat{P}_{j,t}^o = \sum_{i=1}^{M} C_i e^{-y_{j,t}^{o,cc} * t_i^C}. \tag{25}$$

The default intensity $\hat{\lambda}_{j,t}$ is estimated by solving Eq. (20) for $\lambda_{j,t}$,

$$\hat{P}_{j,t}^o = \sum_{i=1}^{M} C_i D'(r_{t,T_{j,t}},\lambda_{j,t},t_i^C) + R'(r_{t,T_{j,t}},\lambda_{j,t},\hat{\delta},t_M^C) \tag{26}$$

where we use the historical recovery rate between 1987–2021 of 34.8% from Moody's (2022) as our estimate of the recovery rate $\hat{\delta}$.

3.2.2. Sustainium bond and estimation of ω

We use the subset of SLBs with no option-linked cash flows to compute the price of a synthetic bond with a sustainability premium but no option-linked cash flows. SLBs with penalty type "Carbon Offset/Donation" have no options embedded and (absent other frictions impacting the price such as liquidity) the yield-to-maturity difference between ordinary bonds and these SLBs is solely due to a convenience of holding the SLB bond. We call these bonds for sustainium-only bonds.

Specifically, for sustainium-only bond j at time t with a yield spread of $s_{j,t}^{SUS}$, and a corresponding synthetic yield spread of an ordinary bond of $s_{j,t}^o$, we estimate the sustainium $\omega_{j,t}^{SUS}$ as:

$$\omega_{j,t}^{SUS} = s_{j,t}^o - s_{j,t}^{SUS}. \tag{27}$$

Using all sustainium-only bond-day observations we estimate the regression

$$\omega_{j,t}^{SUS} = \beta X_{j,t} + \epsilon_{j,t} \tag{28}$$

where $X_{j,t}$ is a vector containing a constant and firm-level characteristics, and compute a firm-time level sustainium for the full sample as

$$\hat{\omega}_{j,t} = \hat{\beta} X_{j,t} \tag{29}$$

where $\hat{\beta}$ is the vector with regression coefficients. The price of a sustainium bond is calculated as

$$\hat{P}_{j,t}^{SUS} = \sum_{i=1}^{M} C_i D(r_{t,T_{j,t}},\hat{\lambda}_{j,t},\hat{\omega}_{j,t},t_i^C) + R(r_{t,T_{j,t}},\hat{\lambda}_{j,t},\hat{\omega}_{j,t},\hat{\delta},t_M^C) \tag{30}$$

where

$$D(r,\lambda,\omega,t) = e^{-(r+\lambda-\omega)t} \tag{31}$$

$$R(r,\lambda,\omega,\delta,t) = \frac{\delta\lambda}{r+\lambda-\omega}\left(1-e^{-(r+\lambda-\omega)t}\right), \tag{32}$$

$\hat{\omega}_{j,t}$ is the sustainium at time t of the bond issuer, and the sustainium bond premium for SLB j at time t is $\hat{P}_{j,t}^{SUS} - \hat{P}_{j,t}^o$.

3.2.3. ESG risk premium and estimation of $E_t^P\left[1_{\{G_T>K\}}\right]$

The implied option price is estimated as (see Eq. (8))

$$\hat{O}_{j,t} = P_{j,t}^{SLB,observed} - \hat{P}_{j,t}^{SUS}. \tag{33}$$

We calculate the ESG premium by estimating $E_t^P\left[1_{\{G_{T_j}^j>K_j\}}\right]$ and inserting the empirical estimates $\hat{O}_{j,t}$ and $\tilde{E}_t^P\left[1_{\{G_{T_j}^j>K_j\}}\right]$ into Eq. (16).

We provide several estimates of $E_t^P\left[1_{\{G_{T_j}^j>K_j\}}\right]$ based on different assumptions about the firm's future ESG commitments. To provide empirical grounding for our estimates, they are based on the firm's historical ESG commitment.

To estimate the firm's historical ESG commitment, we assume that G^j follows a generalized Wiener process,

$$dG_t^j = \mu_j dt + \sigma_j dW_t \tag{34}$$

and at time t we observe historical observations of the factor at times $t_1^j < t_2^j < \cdots < t_k^j < t$ where $t_{i+1}^j - t_i^j$ is one year.[6] To estimate the parameters μ_j and σ_j, we note that $G_T^j - G_t^j \sim N\left(\mu_j(T-t),\sigma_j^2(T-t)\right)$ and estimate the linear regression

$$G_{t+1}^j - G_t^j = \beta + \epsilon_{t+1}, t = t_1^j,\ldots,t_{k-1}^j, \tag{35}$$

where $\epsilon_{t+1} \sim N(0,\xi^2)$. The parameter estimates are then

$$\hat{\mu}_j = \hat{\beta} \tag{36}$$

$$\hat{\sigma}_j = \hat{\xi}. \tag{37}$$

[5] The riskfree rate is the swap rate at time t for the same currency and maturity as the SLB: $r_{t,T_{j,t}} = y_{j,t}^{observed} - s_{j,t}^{observed}$, where the superscript *observed* refers to the actual observed yield-to-maturity and yield spread for SLB j at time t.

[6] We assume an informational lag of 3 months for KPI data. This means that KPI data for year $t-1$ will become available in April of year t. The informational lag differs between firms/SLBs and we choose three as this is a typical lag. The empirical results of Section 5 do not qualitatively change if we use an informational lag of zero or six months.

Based on the historical estimates $\hat{\mu}^h_{j,t}$ and $\hat{\sigma}^h_{j,t}$ (with superscript h to indicate that these are historical estimates), we make different assumptions about the future μ^f and σ^f, and it is then straightforward to calculate $\hat{E}^P_t\left[1_{\{G^j_{T_j}>K_j\}}\right] = P_t\left[G^j_{T_j} > K_j | G^j_{t^j_k}\right]$. Specifically, we include three different assumptions about future firm commitment in our empirical estimates:

- *Same commitment*. In this scenario we assume that the future commitment of the firm is the same as the past, i.e. $\mu^f = \hat{\mu}_{j,t}$ and $\sigma^f = \hat{\sigma}_{j,t}$, and issuing an SLB does not change the ESG behaviour of the firm.
- *Stronger commitment*. In this scenario we assume that the future commitment of the firm is stronger than in the past by assuming that $\mu^f = \min(2\hat{\mu}_{j,t}, 0)$ and $\sigma^f = \hat{\sigma}_{j,t}$. Issuing an SLB incentivizes the firm's ESG efforts through the ESG-linked cash flows in the SLB. Even if the purely pecuniary benefits from reaching the ESG target are modest, as the anecdotal evidence in Section 2 suggests, a firm's choice to issue sustainability-linked bonds may signal a stronger commitment to sustainability. A lower ESG drift captures this increase in effort.
- *Stronger and more focused commitment*. In this scenario we assume that the future commitment of the firm is both stronger and more focused than in the past by assuming that $\mu^f = \min(2\hat{\mu}_{j,t}, 0)$ and $\sigma^f = \frac{1}{2}\hat{\sigma}_{j,t}$. Here, the firm is increasing ESG efforts as well as focussing more on making sure targets are met, for example through increased monitoring.

Most estimates of $\hat{E}^P_t\left[1_{\{G^j_{T_j}>K_j\}}\right]$ are based on relatively few observations of G^j and are therefore noisy. To reduce the noise, we calculate a shrinkage estimator as in Vasiček (1973) and Blume (1975) and calculate in all three scenarios a common time-t probability of missing the target as

$$E^{com}_t = \sum_{j=1}^{N} \hat{E}^P_t\left[1_{\{G^j_{T_j}>K_j\}}\right] \tag{38}$$

where N is the number of targets for which we can calculate a probability at time t. Our time-t estimate of the probability of missing the target under any of three scenarios, $\tilde{E}^P_t\left[1_{\{G^j_{T_j}>K_j\}}\right]$, is then

$$\tilde{E}^P_t\left[1_{\{G^j_{T_j}>K_j\}}\right] = 0.25\hat{E}^P_t\left[1_{\{G^j_{T_j}>K_j\}}\right] + 0.75E^{com}_t. \tag{39}$$

4. Data

In this section we describe the data and Appendix provides further details.

We restrict our sample of corporate bonds to standard fixed-rate bonds with a time-to-maturity of at least six months.[7] We collect price and yield information on all corporate bonds from Bloomberg that are marked as sustainability-linked until the end of our sample period, March 4, 2024. The yield-to-maturity on SLBs is calculated using the current coupon without using the information on potential step-up coupons. For each SLB we look up comparable ordinary bonds (i.e. not green, sustainable, or sustainability-linked) on Bloomberg issued by the same company that have a maturity that is less than four years from the SLB's maturity and have the same currency and seniority. Every day, we select two ordinary bonds that have available yield data and with a maturity closest to but smaller and larger, respectively, than the maturity of the SLB. If it is not possible to find two such bonds, we look for two ordinary bonds that both have either shorter or longer maturity. In this case, we choose the bonds with a time-to-maturity closest to that of the SLB and where the difference in time-to-maturity between the two ordinary bonds is at least six months.

To calculate transactions-based liquidity measures, we extract transactions from the TRACE database for bonds issued by FINRA-regulated firms, typically United States dollar denominated bonds and use the cleaning procedure described in Dick-Nielsen (2009). We augment the TRACE data with transactions for European bonds, done through the solution provided by Propellant.digital B.V. European trading venues are through MIFID II required to disseminate all their transactions in spirit similar to the data collection for the TRACE database, but unlike U.S. transactions, different venues' data come in different formats and are not collected in one database. Propellant provides a software solution that collects the major trading venues' data and allows for one homogeneous data set. Further details are provided in Appendix A.2. There are 17,464 transactions across 8566 bond-days that are overlapping between the TRACE and Propellant data (transactions with identical volume and price on the same day) and to avoid double counting these transactions, we remove the one present in the Propellant data set.

Table 3 shows the coverage of our three main data sources: Bloomberg, TRACE, and Propellant. A bond-day is in the sample if there is Bloomberg data available on that day and therefore the number of bond-days with Bloomberg data in Panel A is equal to the total number of bond-days. Propellant covers more bond-days and bonds than TRACE, while bonds that TRACE covers has more transactions. Panel B shows the number of bond-days with data in different regions and we see that TRACE covers predominantly U.S. while Propellant covers Europe and the coverage of the rest of the world is low. Propellant reports the trading venue where the transaction took place and Panel C shows that the main trading platforms are Bloomberg, Marketaxess and Tradeweb and the three platforms have a fairly similar share of the trading while other platforms have modest transaction activity. Our data sample starts on September 10, 2019; the earliest issuance date of the SLBs in our final sample.

After cleaning the data, the details of which can be found in Appendix A.3, we are left with a final sample that contains 75 SLBs with

Table 3
Data sources. Panel A summarizes the number of bonds covered and the total number of observations (at both the bond-day level and the transaction level for TRACE and Propellant) for each of the three data sources. Panel B breaks down the regional distribution of all bond-days from each source. Panel C shows the same statistics as Panel A, but for each individual venue in the Propellant data set. The data covers the period from September 10, 2019, to March 4, 2024.

Panel A: Data sources overview				
	Bonds	Transactions		Bond-days
Bloomberg	1129	–		551,837
TRACE	81	354,645		32,552
Propellant	366	270,920		79,948
Panel B: Regions				
	EU	US	AS	Other
Bloomberg	213,462	53,222	252,507	32,646
TRACE	10,144	20,287	175	1946
Propellant	72,064	4864	1083	1937
Panel C: Propellant venues				
	Bonds	Transactions	Bond-days	Volume (Millions)
Bloomberg	354	83,021	44,257	65,111.84
Marketaxess	339	66,442	36,330	40,534.62
Tradeweb	330	110,153	46,425	76,149.16
LSE	298	7333	6495	3291.23
Tradeecho	229	3801	2508	2249.17
Tradition	41	158	52	201.33
Liquidnet	7	12	12	11.09

[7] Specifically, we restrict the sample to bonds that have 'At maturity' or 'Callable' as 'Maturity Type' in Bloomberg. For callable bonds, we include only those bonds where the call option is a make-whole call or a fixed-price call restricted to the last 3 months (or less) before the bond matures.

Table 4
SLB sample. This tables shows statistics for the sample of SLBs used in the empirical analysis. Panel A breaks down the SLBs by types of KPI. Panel B show the types of penalties most commonly used in the structuring of SLBs. Finally, Panel C show the distribution of the penalty size for those SLBs that have a coupon step up penalty.

Panel A: KPI type		
	# of SLBs issued	Issuance amount (USD Billions)
GHG (Greenhouse Gas)	65	44.1
Other	20	20.0
Renewables	6	6.8
ESG rating	3	0.6
Diversity	4	3.4
Missing info	0	0.0
Multiple KPIs	17	15.9
Panel B: Penalty type		
	# of SLBs issued	Issuance amount (USD Billions)
Coupon step up	63	60.8
Cash/Redemption	11	10.4
Coupon step up/Down	0	0.0
Carbon offset/Donation	24	3.7
Missing info	0	0.0
Complex	0	0.0
Step down	0	0.0
Panel C: Step up coupon penalty		
	# of SLBs issued	Issuance amount (USD Billions)
=25 BPS	28	30.6
<25 BPS	21	19.4
>25 BPS	14	10.8
No information	0	0.0

98 associated options,[8] a combined issuance amount of 52.53 billion USD, and a total of 24,349 SLB bond-day observations spanning from April 1, 2020, to March 4, 2024. The data sample contains 10.4% of the total number of SLBs in the Bloomberg database and 19.2% of the total issuance amount. We see in Table 4 that the distributions of the KPIs, penalty types, and penalty sizes of coupon step ups in our final sample are similar to those of all SLBs: KPIs related to greenhouse gases are the most common KPI type and the most commonly associated penalty is a coupon step up of 25 bps. Table 5 shows that on average the SLBs have a time-to-maturity of 6.33 years, a coupon of 2.29 and an issuance size of 862$ million.

5. Empirical results

In this section we discuss the pricing of SLBs. We first look at the liquidity of SLBs as well as ordinary bonds issued by the same firm. Then we investigate if SLBs require a premium unrelated to cash flows for being labelled ESG and whether SLBs are mispriced. Finally, we examine determinants of SLB prices and ESG risk premiums.

5.1. Liquidity

The ease with which a corporate bond is traded affects corporate bond prices,[9] and we therefore compare the liquidity of SLBs to that of the corresponding regular bonds. We calculate liquidity of the synthetic ordinary bond as the weighted average liquidity of the two ordinary bonds that are used to calculate the synthetic yield, where the weights for the liquidity measures are the same as those used to determine the synthetic yield.

Table 6 shows the average liquidity of SLB bonds and synthetic ordinary bonds. The transaction-based Amihud measure, trade size and Imputed Roundtrip Cost (IRC) of Feldhütter (2012) suggest that SLBs are more liquid than ordinary bonds: the Amihud measure and IRC are higher and trade size is lower for ordinary bonds. The differences are not statistically significant and the number of bond-days with computable liquidity measures are only a fraction of all bond-days, and different for different measures, so it is difficult to draw conclusions from trade-based liquidity measures that can only be computed conditional on a transaction occurring.

Trade count, trading volume and bond age can be calculated on all bond days and it is clear that SLBs are newer bonds that trade more. The average age of SLBs in our sample is 1.144 years while it is 5.902 years for the ordinary bonds. Given that bonds trade more frequently when they are recently issued, it is not surprising that SLBs trade more often (2.467 pr. day vs. 1.498 pr. day for ordinary bonds) and that the trading volume is higher ($1.517 m pr. day vs. $0.900 m pr. day for ordinary bonds). The differences in age and trading volume are highly significant and it is therefore important to control for the liquidity differences in our results. We do so by adding trade count, volume and age as controls in our regressions (we restrict the controls to those three liquidity measures in order not to reduce the sample size).[10]

5.2. Sustainium

We expect SLBs to trade at higher prices than ordinary bonds issued by the same firm, i.e. a positive SLB premium, since SLBs have potential future additional cash flows. Part of the SLB premium may also be due to ESG investors willing to pay a premium for ESG-friendly securities (Pedersen et al., 2021; Pastor et al., 2021; Feldhütter and Pedersen, 2024 and others). If ESG investors' non-pecuniary benefits accrue solely through ownership as experimental evidence in Bonnefon et al. (2022) suggests, the sustainium may be zero, since SLBs do not finance specific green projects. In contrast, if investors are concerned with the actual impact of their portfolio decisions as in Oehmke and Opp (2024) and Moisson (2022), the sustainium might be significantly positive.

As outlined in Section 3.2.2 we estimate a bond-time sustainium for a subset of SLBs where the penalty is in terms of donations or carbon offset. For these bonds, there are no potential additional payments to bond holders and therefore a yield difference between the SLB and an ordinary bond, $\omega^{SUS}_{j,t} = s^o_{j,t} - s^{SUS}_{j,t}$, can be attributed to the ESG label itself. For these sustainium-only bonds we estimate the regression

$$\omega^{SUS}_{j,t} = \beta X_{j,t} + \epsilon_{j,t} \tag{40}$$

where $X_{j,t}$ is a vector containing a constant, log(size), equity volatility, leverage, profitability, Tobin's q, credit rating, ESG rating, and industry-adjusted ESG rating. Appendix A.4 details the calculation of the variables.

Table 7 shows the regression results. There are three variables that have predictive power for the sustainium: equity volatility, credit rating, and industry-adjusted ESG rating. In the richest specification (6) the sustainium decreases by 1.62 bps for every rating notch. The standard deviation of credit rating is 1.49, so a one standard deviation improvement in rating implies an increase of 2.41 bps in the sustainium (a higher numeric value of credit rating implies a lower credit quality). The positive relation between the sustainium and credit quality has the same sign as the relation between the greenium and credit quality, see Caramichael and Rapp (2024). The table also shows that there is a negative relation between industry-adjusted ESG rating and sustainium. A one standard increase in industry-adjusted ESG rating implies a 2.34 bps lower sustainium (the standard deviation of industry-adjusted ESG rating is 1.28). A potential explanation for the negative relation

[8] There are 6 SLBs with three KPIs, 11 SLBs with two KPIs, and 58 SLBs with one KPI.

[9] See Friewald et al. (2012), Bao et al. (2011), Dick-Nielsen et al. (2012) and Feldhütter (2012) and others.

[10] Specifically, we add $\log(1+L^o_{j,t})-\log(1+L^{SLB}_{j,t})$, where $L^o_{j,t}$ is the weighted average liquidity measure of the two bonds used to determine the synthetic yield on day t for SLB j, and $L^{SLB}_{j,t}$ is the SLB's liquidity measure.

Table 5
Summary statistics for the SLB sample. The distribution of the age, time-to-maturity, coupon, yield-to-maturity, yield spread, and issuance amount for the final sample. There are 24,349 bond-day observations in the period from April 1, 2020 to March 4, 2024.

	Mean	Std	Min	p1	p25	p50	p75	p99	Max
Age (In Years)	1.14	0.77	0.00	0.02	0.50	1.04	1.71	3.13	3.47
TTM (In Years)	6.33	2.47	1.46	2.01	4.36	5.84	8.64	11.78	12.51
Coupon	2.29	1.92	0.00	0.00	0.50	2.25	3.75	7.38	7.88
Yield-to-Maturity	3.57	2.14	−0.37	−0.13	1.19	3.95	5.31	7.12	8.39
Yield spread	1.22	0.92	−0.57	0.05	0.48	1.03	1.70	3.87	4.58
Issuance (USD Millions)	862	514	67	70	500	856	1190	2161	2300

Table 6
Bond liquidity. At the bond-day level we calculate the Amihud measure, IRC measure, average trade size, trade count, volume, and age. The first and second columns show the average for SLBs and a weighted average of ordinary bonds (where the weights are the same as those in Eqs. (23)–(24)), respectively. The Amihud and IRC measures are calculated on a daily basis as in Dick-Nielsen, Feldhütter, and Lando(2012) and we winsorize at the 1% and 99% level. Trade count, total volume, and age are calculated on all bond-days, while average trade size requires at least one transaction on a bond-day to be computable. Additionally, for the Amihud, IRC, and trade size measures, we use a trailing 90-day average as our final daily measure. The third column shows the difference between the two groups on days where both groups have observations, while the fourth shows the number of bond-day pairs with non-missing data. The parentheses show standard errors (clustered at the bond-level) of the difference. *, **, and *** indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

	SLBs	Ordinary bonds	Difference	N
Amihud	0.058	0.077	−0.019	9238
			(0.020)	
IRC	0.209	0.225	−0.015	5555
			(0.048)	
Trade size (Millions)	0.723	0.619	0.104	10,356
			(0.065)	
Trade count	2.467	1.498	0.969**	24,349
			(0.406)	
Volume (Millions)	1.517	0.900	0.617***	24,349
			(0.223)	
Age	1.144	5.902	−4.758***	24,349
			(0.721)	

between sustainium and industry-adjusted ESG rating is that for green firms the "ESG gap" between ordinary bonds and SLBs is smaller as implied by the model in Feldhütter and Pedersen (2024). Finally, a one standard increase in equity volatility implies a 0.45 bps higher sustainium (the standard deviation of equity volatility is 0.23).

We use regression specification (6) in Table 7 to compute a firm-time level sustainium for all firm-time observations as

$$\hat{\omega}_{j,t} = \hat{\beta} X_{j,t}. \tag{41}$$

If the ranges of firm characteristics are substantially different in the full sample compared to the sustainium-only sample, this approach would be problematic because the approach would lead to extrapolation outside the range of the independent variables in the regression. Therefore, Table 8 shows the distribution of the variables for the sustainium-only sample as well as for the remaining sample where the bond coupons are linked to ESG targets. The table shows that firms issuing sustainium-only bonds are smaller, have better credit rating and lower ESG rating than firms using coupon-linked SLBs. The biggest sustainium-only issuers are predominantly Japanese – SingTel, Ajinomoto, Mitsubishi, Daiwa, Shiseido, TDK, ANA, Tokyu, Obayashi, and Asics – while the biggest coupon-linked SLB issuers are international firms — Optus Finance, Novartis Finance, Sanofi, Enel, Analog Devices, Enbridge, Eaton, SK Hynix, Eni, L'Oreal, Air France-KLM and General Mills. Importantly, we see that there is significant overlap in the distribution of all firm-level variables, validating the calculation of the sustainium using the regression in Eq. (41).[11]

The average sustainium is 1.89 bps in the sustainium-only bond sample, 1.18 bps in the coupon-linked SLB sample, and 1.31 bps overall. Thus, the sustainium is small but positive. The sustainium is similar in sign and magnitude as the average green bond premium of 3.37 bps in Feldhütter and Pedersen (2024). Fig. 3 shows the time series of the average sustainium in the complete sample including sustainium-only and coupon-linked SLBs and we see that the sustainium is consistently small and positive.[12]

5.3. SLB premium determinants

Absent frictions and the presence of ESG investors, the value of the embedded conditional cash flows in SLBs will be determined by the size of the cash flows, the probability of the firm missing the target and a potential ESG risk premium. Kölbel and Lambillon (2023) find surprisingly that there is no relation between the penalty size and the SLB premium. If the market does not price SLBs correctly, firm behaviour is unlikely to be aligned with investor ESG preferences.

Table 9 Panel A shows the probabilities of missing the target under the different assumptions about the future commitment of the firm issuing the SLB (outlined in Section 3.2.3). Here, we focus on the subset of SLBs with ESG-linked coupons. The average probability is between 14% and 39% and quite low for both reducing green house gasses (GHG), 15%–37%, and non-GHG targets, 11%–41%. According to industry reports, the historical frequency of missing targets has been low[13] and our results imply that this trend of meeting targets is due to firms setting easy targets. These results support the concern in the ESG market that targets "lack ambition and are too easy to meet" and "are too soft".[14]

Panel B shows that the relation between the SLB premium and the penalty size in our sample is positive and highly significant: the regression coefficient when regressing the SLB premium on penalty size is 1.05–1.17 depending on specification. Thus investors take into account penalty sizes when pricing SLBs and higher penalties translate into

[11] In conversions with bond issuers, they often mention two reasons for issuing sustainium-only bonds, (1) rewarding investors if the firm fails ESG goals creates the wrong investor incentives, and (2) if the coupons are linked to ESG targets, their investors may be forced to treat the overall bond as a derivative and hence regularly mark to market the position from an SPPI perspective (for more on SPPI see https://www.bdo.co.uk/en-gb/insights/business-edge/business-edge-2017/ifrs-9-explained-solely-payments).

[12] At the individual bond-day level, there are a number of negative sustainium observations; 32.0% of the predicted sustainium values are negative. This is noise at the individual bond-day level that is averaged out when aggregating in the cross section as the figure shows.

[13] NatWest report that "based on our tracker of selected public SLBs in the European and US market, 86% were on track to meet their target at the end of 2022" (NatWest, April 18, 2023, "SLB target misses aren't necessarily a negative: it's about the context", https://www.natwest.com/corporates/insights/sustainability/slb-target-misses-arent-necessarily-a-negative-its-about-the-context.html).

[14] Reuters, November 9, 2022, "Explainer: Decoding COP27: the many shades of green bonds" (https://www.reuters.com/business/cop/decoding-cop27-many-shades-green-bonds-2022-11-09/) and GlobalCapital, April 4, 2023, "In defense of SLBs" (https://www.globalcapital.com/article/2bhpp15s781netjeiefi8/sri/green-and-social-bonds-and-loans/in-defence-of-slbs).

Table 7

Sustainium determinants. There are 24 SLB bonds issued by 18 firms with 4509 bond-day observations with no option-linked cash flows in the sample period 2020:04–2024:03. This table shows results of a regression of the SLB premium (in basis points) on firm characteristics for this subsample. The liquidity controls are $\frac{1}{N_t^{SUS}}\sum_{j=1}^{N_t^{SUS}}\left(\log(1+L^o_{i,j,t})-\log(1+L^{SUS}_{i,j,t})\right), i=1,\ldots,3$ where $L^{SUS}_{i,j,t}$ ($L^o_{i,j,t}$) is the value of liquidity variable i on day t for SLB j with no cash flow effects (ordinary bond) and the three liquidity variables are trade count, trading volume and bond age. Standard errors clustered at the bond level are in parentheses and *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 level, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	17.01	8.22	7.17	20.59	9.45	10.18
	(21.61)	(21.97)	(18.87)	(16.84)	(20.28)	(16.45)
Log(size)	1.19	1.03	1.08	1.21	1.04	1.09
	(1.73)	(1.85)	(1.79)	(1.74)	(1.85)	(1.78)
Equity vol	1.97***	1.95***	2.00***	1.92***	1.93***	1.94***
	(0.29)	(0.23)	(0.29)	(0.33)	(0.29)	(0.33)
Leverage	−11.06	−8.39	−8.44	−11.92	−8.67	−9.13
	(11.53)	(10.83)	(10.02)	(10.25)	(10.27)	(9.17)
Profitability	−7.13	−4.60	−6.70	−9.41	−5.59	−9.30
	(15.81)	(14.04)	(14.92)	(13.31)	(12.46)	(12.51)
Tobin's q	−3.51	−1.13	−3.81	−3.60	−1.13	−3.95
	(3.41)	(2.72)	(3.34)	(3.39)	(2.72)	(3.29)
Credit rating	−1.54***	−1.23**	−1.41***	−1.74***	−1.31*	−1.62**
	(0.40)	(0.57)	(0.48)	(0.65)	(0.73)	(0.68)
Industry-adj ESG rating	−1.47**		−1.73***	−1.53*		−1.83***
	(0.72)		(0.62)	(0.79)		(0.66)
ESG rating		−0.63	1.92		−0.60	2.14
		(2.55)	(2.36)		(2.60)	(2.35)
Liquidity controls	No	No	No	Yes	Yes	Yes
R^2	0.168	0.130	0.173	0.172	0.131	0.178
N	4509	4509	4509	4509	4509	4509

Table 8

SLB and sustainium bond issuer characteristics. There are 75 SLB bonds issued by 41 firms with 24,349 bond-day observations in the sample period 2020:04–2024:03. There are 24 SLB bonds issued by 18 firms with 4509 bond-day observations with no option-linked cash flows in the sample period 2020:04–2024:03, called sustainium bonds. The remaining SLB bonds have option-linked cash flows, called coupon-linked SLBs. This table shows the distribution – across bond-days – of firm characteristics in the two samples. Standard errors clustered at the bond level are in parentheses and the last column tests for a difference in means and *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 level, respectively.

	Coupon-linked SLBs						Sustainium-only bonds						Mean diff
	Mean	q5	q25	q50	q75	q95	Mean	q5	q25	q50	q75	q95	
Log(size)	10.47	8.51	9.52	10.89	11.21	12.09	9.12	6.49	8.34	9.26	9.66	12.63	1.35***
	(0.16)						(0.35)						(0.38)
Equity vol	0.12	0.01	0.01	0.02	0.14	0.47	0.12	0.01	0.01	0.02	0.02	1.65	0.01
	(0.03)						(0.09)						(0.10)
Leverage	0.47	0.11	0.41	0.50	0.59	0.68	0.39	0.00	0.23	0.33	0.57	0.77	0.08
	(0.03)						(0.06)						(0.06)
Profitability	0.14	0.05	0.07	0.10	0.22	0.32	0.20	-0.04	0.07	0.18	0.29	0.58	−0.05
	(0.01)						(0.04)						(0.04)
Tobin's q	0.02	0.01	0.01	0.01	0.01	0.02	0.10	0.01	0.01	0.01	0.01	1.10	−0.08
	(0.01)						(0.09)						(0.09)
Industry-adj ESG rating	6.92	2.30	5.60	7.90	8.80	10.00	6.69	4.60	6.00	6.90	8.10	8.40	0.23
	(0.42)						(0.28)						(0.50)
ESG rating	6.07	4.00	5.40	6.30	7.20	7.40	5.52	4.60	5.10	5.50	5.90	6.50	0.55**
	(0.20)						(0.13)						(0.24)
Credit rating	8.60	6.00	8.00	8.00	9.00	12.00	6.68	4.00	6.00	7.00	8.00	9.00	1.92***
	(0.27)						(0.35)						(0.44)

higher bond prices as basic financial theory implies. Furthermore, we see that the interaction between the penalty size and the probability of missing the target is positive in all specifications, as expected, between 1.05–1.92, and statistically significant in half of the specifications.

We also see in Panel B that equity volatility is a firm-specific characteristic that consistently has statistical significance in explaining the SLB premium: a higher equity volatility implies a higher SLB premium. A potential explanation is that different types of uncertainty are correlated and equity volatility is correlated with uncertainty about meeting the target. Indeed, we find that there is a positive correlation between equity volatility and σ_j in Eq. (34).[15] Since σ_j is based on relatively few data points and updated on an annual basis (when a new historical observation of the factor is released) while equity volatility is updated on a daily basis, equity volatility will provide current information about σ_j and thus the probability of missing the target. While beyond the scope of this paper, calculating the probability of missing the target using information from both historical observations of the KPI as well as current financial data is an interesting topic for future research.

5.4. Are SLBs mispriced?

The existing literature on SLBs finds that they are mispriced. Kölbel and Lambillon (2023) conclude that the yield difference between on ordinary bond and an SLB issued by the same issuer exceeds the maximum potential penalty (expressed in yield) that issuers need to pay in case the target is not reached. This implies that even if the market prices an SLB with a probability of one of missing the target, the SLB price is higher than that of an ordinary bond with same (ordinary and penalty) coupons and SLBs are overpriced. In contrast (Berrada

[15] Since different G_j's have different scales, we calculate a scaled version as $\sigma_j^{scaled} = \log(\frac{\sigma_j}{G_t - K})$ and the correlation in the panel of σ_j^{scaled} and equity volatility is 0.07 both at the KPI-level and at the bond level (where we compute an average σ_j^{scaled} for bonds with multiple KPIs.).

Table 9
SLB premium determinants. Panel A shows the average estimated probability of meeting the ESG target. 'GHG' is the subsample of targets that are related to green house gasses, while 'non-GHG' are all other targets. In Panel B the SLB premium is regressed on explanatory variables. The liquidity controls are $\log(1+TC^{o}_{j,t})-\log(1+TC^{SLB}_{j,t})$, $\log(1+V^{o}_{j,t})-\log(1+V^{SLB}_{j,t})$, and $\log(1+A^{o}_{j,t})-\log(1+A^{SLB}_{j,t})$, where $TC_{j,t}$ is the trade count, $V_{j,t}$ is the volume, and $A_{j,t}$ is the age for ordinary bond (superscript o) j and SLB (superscript SLB) j on day t. Standard error clustered at the bond level are in parentheses, the number of observations in square brackets (in Panel A), and *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 level, respectively.

Panel A: Probability of missing target

	All	GHG	non-GHG
Same	0.39***	0.37***	0.41***
	(0.01)	(0.01)	(0.02)
Stronger	0.14***	0.16***	0.11***
	(0.02)	(0.03)	(0.02)
Stronger & Focused	0.14***	0.15***	0.12***
	(0.01)	(0.01)	(0.02)
N	[19,840]	[12,354]	[7486]

Panel B: Determinants of SLB premium

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	3.56	5.85	6.53	5.89	0.16	2.05	2.15	1.57
	(6.01)	(5.80)	(6.18)	(6.21)	(4.95)	(4.79)	(4.96)	(4.96)
Penalty size	1.20***				1.07***			
	(0.33)				(0.28)			
Penalty × Prob (Same)		1.86**				1.55**		
		(0.74)				(0.66)		
Penalty × Prob (Stronger)			1.05				1.08	
			(0.89)				(0.80)	
Penalty × Prob (More Focused)				1.92				1.87*
				(1.23)				(1.11)
Log(size)	−0.08	−0.14	−0.13	−0.11	−0.01	−0.06	−0.04	−0.03
	(0.33)	(0.32)	(0.34)	(0.35)	(0.29)	(0.29)	(0.29)	(0.30)
Equity Vol	0.62*	0.82***	0.93***	0.89***	0.58**	0.76***	0.85***	0.81***
	(0.32)	(0.32)	(0.33)	(0.33)	(0.29)	(0.29)	(0.29)	(0.30)
Leverage	0.29	0.18	0.48	0.34	−0.86	−1.03	−0.91	−1.05
	(1.11)	(1.20)	(1.34)	(1.32)	(1.30)	(1.31)	(1.40)	(1.40)
Profitability	−3.11	−4.97	−5.91	−5.58	−1.17	−2.83	−3.39	−3.08
	(3.38)	(3.66)	(3.93)	(3.84)	(3.09)	(3.27)	(3.43)	(3.35)
Tobin's q	−0.75	−1.41	−1.71*	−1.67*	−1.25*	−1.85**	−2.21**	−2.15***
	(0.65)	(0.78)	(0.97)	(0.89)	(0.67)	(0.74)	(0.88)	(0.82)
Industry-adj ESG rating	0.06	0.16	0.20	0.17	−0.03	0.06	0.10	0.07
	(0.14)	(0.16)	(0.18)	(0.17)	(0.11)	(0.13)	(0.14)	(0.13)
ESG rating	−0.38	−0.60	−0.66	−0.60	−0.09	−0.28	−0.32	−0.25
	(0.44)	(0.50)	(0.54)	(0.52)	(0.38)	(0.42)	(0.46)	(0.43)
Credit rating	−0.14	−0.17	−0.18	−0.17	0.03	0.01	0.03	0.05
	(0.20)	(0.19)	(0.21)	(0.21)	(0.19)	(0.19)	(0.20)	(0.20)
Liquidity controls	No	No	No	No	Yes	Yes	Yes	Yes
R^2	0.18	0.12	0.07	0.08	0.24	0.19	0.17	0.17
N	19,840	19,840	19,840	19,840	19,840	19,840	19,840	19,840

Table 10
Mispricing. Panel A shows the average estimate of the ordinary bond $P^{o}_{j,t}$ in Eq. (11), the "sustainium bond" $P^{SUS}_{j,t}$ in Eq. (9), and the observed bond price $P^{SLB}_{j,t}$. Panel B shows if the SLB premium is significantly different from the upper bound of the option value as well as zero (in which case $P^{SLB}_{j,t} = P^{o}_{j,t}$). There are 19,840 bond-day observations and standard errors are clustered at the bond-level and *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 level, respectively.

Panel A: Average prices

	Mean	
$P^{o}_{j,t}$	90.93	
$P^{SUS}_{j,t}$	90.99	
$P^{SLB}_{j,t}$	91.51	
Panel B: Mispricing test		
SLB price premium	0.58***	−0.01
	(0.18)	(0.15)
UB - SLB price premium	0.46***	1.04***
Liquidity controls	No	Yes
N	19,840	19,840

et al., 2022) find that SLBs trade at lower prices than ordinary bonds on average, i.e. SLBs are underpriced on average.[16]

We revisit these conflicting results by relying on a mispricing measure similar to that proposed by Berrada et al. (2022). For a given bond at time t the measure is given as

$$Mispricing_t = \frac{P^{SLB}_t - P^{o}_t}{O^{UB}_t} \tag{42}$$

where P^{SLB}_t is the SLB price, P^{o}_t is the price of an ordinary non-ESG bond given in Eq. (11), and O^{UB}_t is the upper bound in Eq. (14). If the mispricing measure is greater than one, the SLB price premium is greater than the sum of all penalties and the SLB is overpriced. If the measure is less than zero, the SLB premium is negative and the SLB is underpriced. For values between zero and one there is no mispricing.

Table 10 Panel A shows summary stats for the variables used in calculating the mispricing measure. The average ordinary bond price is 90.93 while the average sustainium-only bond price is 90.99 (i.e. an average sustainium of 1.28 bps in yield space documented in Section 5.2

[16] Berrada et al. (2022) also finds that a subset of SLBs are overpriced.

Table 11
ESG risk premium. Panel A shows the average ESG risk premium given in Eq. (16). 'GHG' is the subsample of targets that are related to green house gasses, while 'non-GHG' are all other targets. If an SLB has multiple targets, it is included in the GHG sample if all options are GHG related, else it is included in the non-GHG sample. Panel B shows regressions with the ESG risk premium on the lefthand side. The credit rating variables measures the bond's credit rating and takes the value 1 for AAA, 2 for AA+, 3 for AA, … , 21 for C. The liquidity controls are $\log(1+TC^o_{j,t})-\log(1+TC^{SLB}_{j,t})$, $\log(1+V^o_{j,t})-\log(1+V^{SLB}_{j,t})$, and $\log(1+A^o_{j,t})-\log(1+A^{SLB}_{j,t})$, where $TC_{j,t}$ is the trade count, $V_{j,t}$ is the volume, and $A_{j,t}$ is the age for ordinary bond (superscript o) j and SLB (superscript SLB) j on day t. Standard error clustered at the bond level are in parentheses, the number of observations in square brackets (in Panel A), and *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 level, respectively. Regressions (1) and (4), (2) and (5), and (3) and (6) use the ESG premium as calculated with the same, stronger, and stronger & focused commitment assumptions, respectively.

Panel A: ESG risk premium

	All	GHG	non-GHG
Same	−0.22	0.03	−0.63
	(0.19)	(0.17)	(0.41)
Stronger	−0.41**	−0.14	−0.85**
	(0.20)	(0.18)	(0.41)
Stronger & Focused	−0.42**	−0.15	−0.86**
	(0.20)	(0.18)	(0.41)
N	[19,840]	[12,354]	[7486]

Panel B: Determinants of the ESG risk premium

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−7.57	−7.17	−7.12	−2.99	−2.39	−2.34
	(6.52)	(6.77)	(6.77)	(5.18)	(5.40)	(5.40)
VIX	2.01	1.89	1.94	1.97	1.86	1.91
	(1.31)	(1.34)	(1.35)	(1.34)	(1.35)	(1.35)
Log(size)	0.25	0.22	0.22	0.17	0.13	0.13
	(0.36)	(0.37)	(0.37)	(0.30)	(0.31)	(0.31)
Equity Vol	−0.75**	−0.77**	−0.77**	−0.67**	−0.68**	−0.68**
	(0.35)	(0.36)	(0.36)	(0.31)	(0.31)	(0.31)
Leverage	−0.88	−0.94	−0.96	0.58	0.60	0.58
	(1.30)	(1.34)	(1.35)	(1.38)	(1.43)	(1.43)
Profitability	5.73	5.81	5.80	3.10	3.08	3.08
	(4.09)	(4.14)	(4.13)	(3.53)	(3.57)	(3.56)
Tobin's q	1.06	1.16	1.16	1.57**	1.69**	1.69**
	(0.84)	(0.87)	(0.88)	(0.79)	(0.81)	(0.81)
Industry-adj ESG rating	−0.26	−0.25	−0.25	−0.15	−0.14	−0.15
	(0.18)	(0.18)	(0.18)	(0.14)	(0.14)	(0.14)
ESG rating	0.74	0.71	0.71	0.38	0.34	0.34
	(0.56)	(0.56)	(0.56)	(0.46)	(0.46)	(0.46)
Credit rating	0.14	0.13	0.13	−0.08	−0.10	−0.10
	(0.22)	(0.23)	(0.23)	(0.21)	(0.21)	(0.21
Liquidity controls	No	No	No	Yes	Yes	Yes
R^2	0.08	0.08	0.08	0.18	0.19	0.19
N	19,840	19,840	19,840	19,840	19,840	19,840

translates into 6 bps in price space). The SLBs have a price that is on average $0.58 higher for a face value of $100 than an ordinary bond.

We test if there is mispricing in Table 10 Panel B. The table shows that without liquidity controls the average SLB price premium is significantly higher than zero and significantly below the upper bound. The SLB price premium reduces when controlling for bond liquidity, but the conclusion that there is no statistical evidence for mispricing remains.

Fig. 4 shows the mispricing measure over time. The figure shows that there are periods in 2022–2023 where the mispricing measure is less than zero, but the underpricing is short and statistically insignificant. In the last part of the sample, the mispricing measure is slightly greater than one, but again the distance to the mispricing bound of one is statistically insignificant. Overall, we find no evidence that SLBs are mispriced.

Why are our results different from the existing literature? First, Berrada et al. (2022) and Kölbel and Lambillon (2023) focus on pricing of SLBs in the primary market, while we focus on pricing in the secondary market. Second, and perhaps more importantly, our matching procedure is different from theirs. Kölbel and Lambillon (2023) compare the yield-at-issuance of an SLB with the yield-at-issuance with an ordinary bond issued by the same firm with the closest issue date, maturity and issue size. On average, the issuance date of the SLB is 528 days later than the ordinary bond in their sample and this difference is likely to introduce systematic noise due to changes in macro-economic variables such as interest rates and macro-economic uncertainty. For example, the average issuance date of the ordinary bonds in their matched sample is March 2020 – when Covid shocked markets – while the average issuance date of the SLBs is September 2021, a significantly more calm period. This may explain why they find a "free lunch", i.e. that the prices of SLBs are so high that on average the mispricing measure is higher than one. Berrada et al. (2022) discount SLB cash flows without the penalty with sector curves estimated using bonds with the same rating issued by firms in the same industry and find that on average SLB prices are lower, i.e. a mispricing measure lower than zero. Within a rating category there is a wide range of yields and the sector curve yield might therefore not reflect the yield of the SLB issuer with sufficient accuracy, leading to a noisily estimated mispricing measure. In contrast, our approach carefully matches the secondary market SLB yield with an interpolated yield from non-SLB bonds with similar maturity from the same issuer on the same day, leading to more precise estimates.

5.5. ESG risk premium

The SLBs in our sample span a range of distinct ESG targets and some may command a risk premium. Since targets related to emission of greenhouse gasses are most common we separate them into GHG and non-GHG. It is not clear if there is a GHG risk premium and if so what sign it is expected to have. On one hand emissions of GHGs contribute to global warming and if there is a global lack of coordination in reducing GHGs, emissions increase more than expected resulting in increased risk of states with low consumption due to climate disasters. In this case, the embedded options in SLBs are a hedge against climate risk because the firm is more likely to miss the target in such bad states of the world, leading to extra bond cash flows, and SLBs have a negative

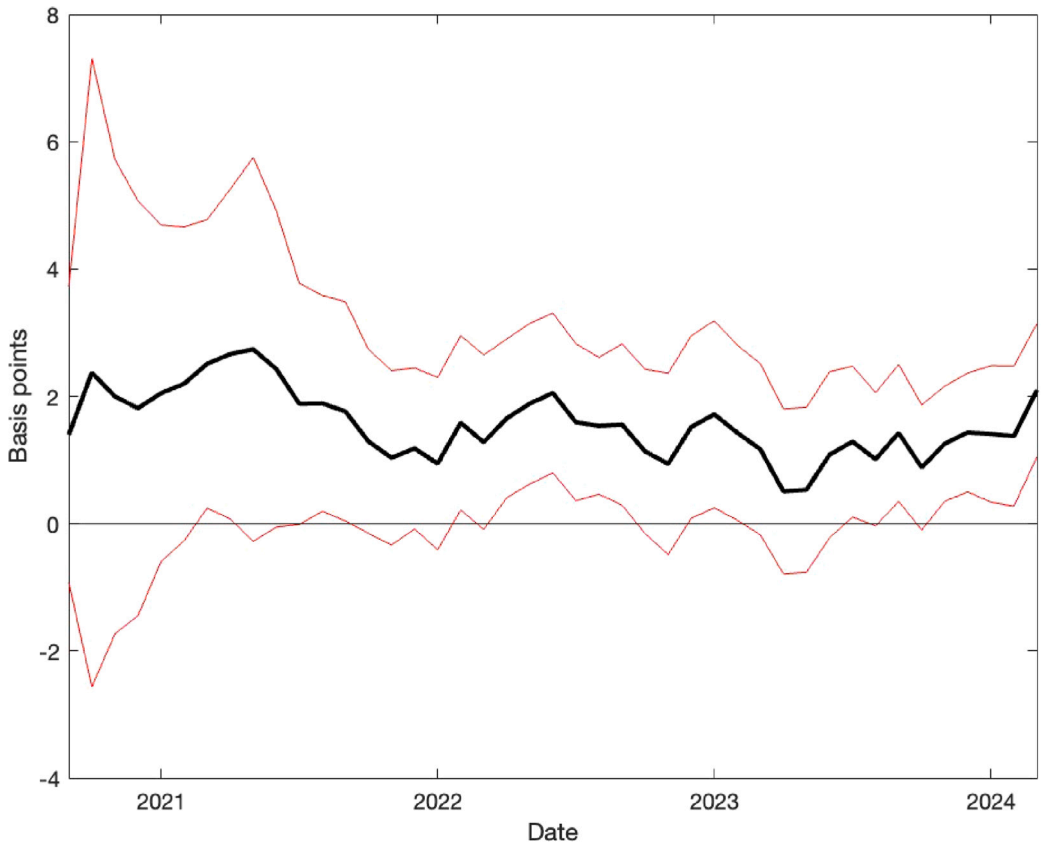

Fig. 3. *Yield sustainium.* A raw sustainium is estimated by calculating the yield difference between the yield of non-SLBs and the yield on a subset of SLBs with the feature that their coupon is not tied to the issuing firm reaching a sustainability target (instead the firm donates money to sustainability-linked causes). For that sample the raw sustainium is regressed on firm-level characteristics and a predicted sustainium is computed for all firms using the regression coefficients. The graph shows the monthly average predicted sustainium for months with at least four bonds in the sample period with a 95% confidence band using standard errors clustered at the bond level.

risk premium. On the other hand high economic activity may result in large emissions of GHGs which in turn make it more likely that the SLB option ends in the money. Here, the option pays of in a good state of the world – in terms of consumption – and investors may require a positive risk premium.[17]

Since we are interested in the risk premium related to cash flow risk, we estimate the risk premium as the expected value of the optional cash flows minus the market price of those cash flows as outlined in Section 3.2.3. Table 11 Panel A shows the average ESG risk premium and we see that the point estimates are mostly negative, and statistically significant in some specifications, consistent with the embedded option being a hedge against ESG risk. However, when we focus on SLBs with GHG targets, the average risk premium is statistically insignificant and the sign is not consistently negative, suggesting that the negative risk premium is not due to hedging of climate risk. For non-GHG SLBs the risk premium is significantly negative in some specifications. The non-GHG targets include a range of different ESG areas and this suggests that ESG risks unrelated to climate change are priced.[18]

Turning to determinants of the risk premium, Panel B shows that there is no significant relation between the ESG risk premium and risk premiums in general — as measured through the VIX. The only firm characteristics that have significant explanatory power for the risk premium across specifications is equity volatility and a higher equity volatility implies a more negative ESG risk premium.

6. Conclusion

A major issue in global financial markets is how to speed up the shift to a greener and more socially inclusive economy. Aligning financial incentives of companies with ESG incentives is a critical component of the solution, and sustainability-linked bonds (SLBs) have recently emerged as a class of securities that can support such alignment. Because SLB cash flows are directly linked to achieving future ESG goals, they encourage issuing companies to take ESG-conscious actions.

Financial market practitioners, regulators, NGOs and academics are concerned that SLBs do not work as intended. Firms may chose easy targets that reflect "business-as-usual" and the ESG-related option element may be difficult to price and the bonds overpriced. If this is the case, SLBs will not work as intended and may even hinder firms' transition to a greener economy. We provide a flexible theoretical framework for pricing SLBs that includes credit risk, investor preferences for sustainable securities, the likelihood that the firm will fulfil the target and the penalty size in order to analyse these important concerns.

SLB cash flows are identical to cash flows of an ordinary fixed-rate bond plus ESG-linked cash flows that only pay out if a combination of ESG targets are not reached. Absence of mispricing requires that the value of the ESG-linked cash flows is greater than zero but less than the sum of potential cash flows. Empirically, we find that SLBs on average satisfy these "no-mispricing" bounds, in contrast to existing literature. Also, we find that the value of the ESG option embedded in SLBs is strongly related to the size of the penalty. Overall, our empirical results indicate no mispricing.

[17] See Giglio et al. (2021) for an extensive review.

[18] Besides those mentioned in Section 2, examples include number of electric vehicle charging points installed in managed infrastructure (Abertis), reduction in the amount of packaging placed on the market (Carrefour), increasing amount of recycled plastic usage (Hera), increase patient outreach/access (Novartis), and reducing industrial water withdrawal intensity (Suzano).

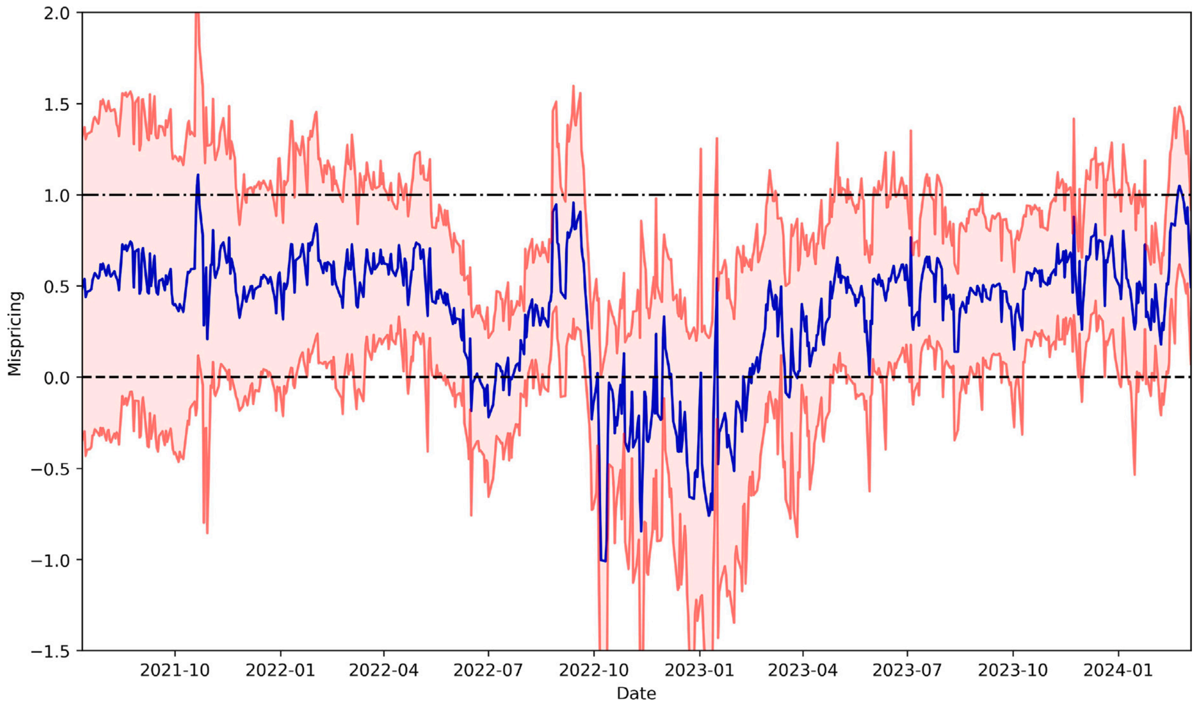

Fig. 4. *Mispricing.* The figure shows the time series variation of the mispricing measure for the SLB premium. On each day in the sample where we have at least ten observations we compute the mispricing measure as the average SLB premium on that day divided by the average upper bound on the same day and the figure shows the time series variation.

We also find that firms set targets that are easy to reach: the average probability of meeting the target in our sample period is 61%–86%. Furthermore, we find that investors are willing to accept a 1–2 bps lower yield due to SLBs ESG label, providing new empirical evidence showing that impact investing matters for asset prices. Finally, we estimate the ESG premium as the expected value of the potential penalty minus the extracted market price. The ESG premium is negative, and statistically significant under some assumptions, providing evidence that SLBs can be used as financial hedges against ESG risk.

CRediT authorship contribution statement

Peter Feldhütter: Writing – review & editing, Writing – original draft, Formal analysis. **Kristoffer Halskov:** Writing – review & editing, Writing – original draft, Formal analysis. **Arthur Krebbers:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors have nothing to disclose.

Data availability

Pricing of Sustainability-Linked Bonds Dataset (Reference data) (Mendeley Data)

Appendix. Data

In this Appendix we discuss in more detail how we clean the data.

A.1. Bloomberg

Bloomberg has several data sources available and we prioritize the data sources in the order: 'CBBT', 'BGN', 'BMRK', and 'BVAL'. That is, for a given bond-day, we extract price and yield spread information from CBBT, and if there is none, we try BGN, and so on. We use Bloomberg's I-spread as yield spread, which uses the relevant swap rate in the same currency as the bond when calculating the spread.

A.2. Propellant

The Propellant data used in the paper covers transactions from: Bloomberg, London Stock Exchange, Marketaxess, Tradeecho, Tradeweb, Tradition, and Liquidnet. We clean the Propellant data the following way:

1. Multiple amended trades ('AMND' = True) point to the same 'ORIGINAL_TRANSACTION_IDENTIFICATION_CODE', so we only keep the last amended trade for a given 'ORIGINAL_TRANSACTION_IDENTIFICATION_CODE' and drop any amended trades without one.
2. Drop trades without any 'TRADING_DATE_AND_TIME' and 'PRICE' information.
3. Drop cancelled trades ('CANC' = True).
4. Drop all observations that are not in the percentage of par price format ('PRICE_NOTATION' ≠ 'PERC').
5. Drop entries with extreme prices (below 10 and above 1000). These are mostly due to wrong price information due to a misplaced decimal point.
6. There is no volume cap in the Propellant data set, however, since there is a volume cap on TRACE data of 5,000,000, we impose the same cap on the Propellant data for comparability.

Table A.1 below shows the amount of transactions that are removed at each step of the cleaning process described above.

A.3. Final sample

To arrive at the final sample used in our empirical analysis, we first discard all SLB bond-days after the bond's first option target date. Next, we remove SLB bonds from the sample if there are less than 20 bond-day observations for the bond. Also, we discard a bond-day if we are not able to calculate the price of an ordinary bond ($P_{j,t}$), the price of a sustainium bond ($P_{j,t}^{SUS}$), and – for the SLBs with ESG-linked coupons – the physical option value $\sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_t^P\left[1_{\{G_{T_j}>K\}}\right] D(r_{t,T},\lambda_t,\omega_t,t_i^j)$. In

Table A.1
Cleaning process of the Propellant data set. This table shows the number of transactions that are removed at each step of the cleaning process, as well as how many transactions remain afterwards. The description of each step can be found in the text.

Cleaning step	# of transactions removed	# of transactions remaining
Uncleaned data	–	382,766
Step 1	2723	380,043
Step 2	65,199	314,844
Step 3	4891	309,953
Step 4	9479	300,474
Step 5	188	300,286
Step 6	–	300,286

particular, this implies that we can compute the firm characteristics $X_{j,t}$ in Eq. (29) on day t for the firm issuing bond j and we have at least three historical observations of the ESG factor such that we can calculate $E_t^P\left[1_{\{G_{T_j}>K\}}\right]$. For sustainium-only bonds, we require that we can compute the firm characteristics $X_{j,t}$ in Eq. (29) on day t for the firm issuing bond j. Finally, we exclude the bond with Bloomberg ticker 'BS422627 Corp' because the bond prices in Bloomberg are not consistent with the reported yield-to-maturity.

A.4. Calculation of firm characteristics

Since we are dealing with a sample of global firms, we use Compustat to gather both price and accounting data. This requires finding the unique GVKEY of each firm in our sample, which has been done manually. All accounting data has been lagged 3 months to avoid look-ahead bias. Furthermore, all accounting data have been converted to USD by following the "*Currency Translation*" guide provided by Compustat. The following list details the calculation of the eight firm characteristics used in Section 5 of the paper:

1. **Log(Size):** $\log(E_{it}^M)$, where E_{it}^M is the market value of equity calculated as "*Common Shares Outstanding*" times "*Price - Close - Daily*" for firm i at time t.
2. **Equity Volatility:** $\sqrt{\frac{1}{21}\sum_{t=1}^{21}(r_{it}-\bar{r}_i)^2}$, where r_{it} is the equity return of firm i at time t and $\bar{r}_i$ is the average equity return over the past 21 days for firm i. Returns are calculated using the daily prices from Compustat, adjusted for dividends and stock buybacks/issuance/splits.
3. **Leverage:** $\frac{D_{it}^S+D_{it}^L}{E_{it}^M+D_{it}^S+D_{it}^L}$, where D_{it}^S and D_{it}^L is "*Debt in Current Liabilities*" and "*Long-Term Debt - Total*", respectively.
4. **Profitability:** $\frac{R_{it}-C_{it}}{A_{it}}$, where R_{it}, C_{it}, and A_{it} is "*Revenue - Total*", "*Cost of Goods Sold*", and "*Assets - Total*", respectively.
5. **Tobin's Q:** Defined as $\frac{E_{it}^M+L_{it}^M}{E_{it}^B+L_{it}^B}$, where E and L refer to the equity and liabilities values of the firm, respectively, while the superscripts M and B indicates the market and book values, respectively. Because we do not have data on the total market value of a firm's liabilities, we let $L_{it}^M = L_{it}^B$. The book value of equity, E_{it}^B, is calculated as "*Stockholder's Equity*" plus "*Deferred Taxes and Investment Tax Credit*" minus "*Preferred/Preference Stock (Capital) - Total*". Missing values of "*Stockholder's Equity*" and "*Preferred/Preference Stock (Capital) - Total*" are set to 0 and equity book values below 0 are set to 0. The book value of liabilities, L_{it}^B, is "*Liabilities - Total*". Finally, the variable is scaled by dividing with 100.
6. **Credit Rating:** Extracted manually from Bloomberg and converted to a numerical value such that a higher number corresponds to a lower credit rating, i.e. $AAA = 1$, $AA+ = 2$, ..., $C = 21$.
7. **ESG Rating:** Numerical ESG rating extracted from MSCI. Values are between 0 and 10 with a higher number corresponding to a more green and sustainable firm.
8. **Industry-Adjusted ESG Rating:** Numerical (industry demeaned) ESG rating extracted from MSCI.

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