Pricing of Sustainability-Linked Bonds*

Peter Feldhütter†
Copenhagen Business School

Kristoffer Halskov‡
Copenhagen Business School

Arthur Krebbers§
University of Strathclyde

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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 4–7bps lower yield due to the bond's ESG label, providing evidence of investors caring about environmental impact. Furthermore, we find the average probability of meeting the target is 73% 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.

Keywords: ESG, Sustainability-linked bond; Corporate bonds; Step-up coupon; sustainium

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†Department of Finance, Copenhagen Business School, Solbjerg Plads 3, A4.02, 2000 Frederiksberg pf.fi@cbs.dk

‡Department of Finance, Copenhagen Business School, Solbjerg Plads 3, D4.17, 2000 Frederiksberg kh.fi@cbs.dk

§Department of Accounting Finance, Strathclyde Business School, 199 Cathedral Street, Glasgow G4 0QU. arthur.j.krebbers@strath.ac.uk

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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 premium as the price difference between SLB and synthetic identical "brown bonds" with no additional ESG-related cash flows and find 1) investors are willing to pay a premium for the ESG label itself, 2) there is a strong relation between the SLB premium and the penalty size for missing the target, 3) the average SLB premium is less than the sum of penalties, i.e. "no arbitrage", 4) the average probability of meeting the target is high at 73%, and 5) suggestive evidence that SLBs serve as hedges against ESG risk.

We calculate the SLB 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 "brown" bond and an SLB, both issued by the same firm. Specifically, on a daily basis, we match each SLB with two "brown" bonds that have a longer and shorter maturity and interpolate the brown bonds' yield spreads to generate a

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non-SLB synthetic yield spread with the same maturity as the SLB. The difference between the synthetic yield spread and the SLB yield spread is the SLB yield premium. We convert the SLB yield premium to an SLB price premium,

$$\text{SLB premium} = \text{SLB price - ordinary bond price},$$

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 (2022)) 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 SLB premium – which we call the sustainium – for this subset of SLBs providing empirical support for the importance of impact investing. Interestingly, the sustainium is of similar size as the green bond premium, suggesting that indirect ownership and impact investing have a similar impact on asset prices.

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 premium. We find that the SLB 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

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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 was the "risk of greenwashing".[2] If correct, firms can engage in greenwashing behavior 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 calculate the probability that the future target will be missed. This approach essntially assumes that future ESG improvements are similar to historical improvements and we find that the average probability of missing the target is only 27%. 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. We compute the price of the optional ESG cash flows as

$$\text{ESG cash flow price} = \text{SLB premium - sustainium},$$

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

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

[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.

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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 macroeconomic shock (Bansel, Kiku, and Ochoa (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.

The average risk premium point estimate is negative and the absolute value is 29% of the total SLB premium, but statistically insignificant, providing suggestive evidence that SLBs serve as financial hedges against ESG risk. We also find that the risk premium is significantly lower for higher rated firms, showing that the negative risk premium is predominantly earned by higher-rated firms.

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

[3]See Giglio, Kelly, and Stroebel (2021) for an extensive review.

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and issuer-specific credit risk introduces 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. Berrada, Engelhardt, Gibson, and Krueger (2022) provide a theoretical framework for understanding the relation between firm effort and size of penalties. Erlandsson and Mielnik (2022) provides 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. In Section 4 we describe the data while the estimation approach is laid out in Section 5. Section 6 describes the empirical results and Section 7 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 behavior 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

[4] More broadly, there is a growing literature on green bonds including Zerbib (2019), Baker, Bergstresser, Serafeim, and Wurgler (2022), Caramichael and Rapp (2022)), Flammer (2021), and Larcker and Watts (2020). Pedersen, Fitzgibbons, and Pomorski (2021), Pastor, Stambaugh, and Taylor (2021) and Feldhütter and Pedersen (2022) investigate pricing in presence of ESG investors and Engle, Giglio, Kelly, Lee, and Stroebel (2020), Ilhan, Sautner, and Vilkov (2021), Huynh and Xia (2021), Seltzer, Starks, and Zhu (2022), Bolton and Kacperczyk (2021), Bolton and Kacperczyk (2022), Oehmke and Opp (2022) and Avramov, Cheng, Lioui, and Tarelli (2022) look at the pricing of ESG risk.

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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 Figure 1.

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 Figure 2. Both the number and notional amount issued have dramatically increased, as shown in Panel A. Between 2018 and August, 2022, 632 SLBs have been issued, most of them in 2021 and 2022. The total notional amount issued for the 632 SLBs is 354.6 USD billions. Panel B shows that the majority of the bonds, 64 percent, were issued in Europe, followed by 19 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 concerned with maintaining or raising a company's ESG rating. A significant number of KPIs are 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. 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 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. KPI data is missing for 59 SLBs, 5.1% of the total amount of issuance.

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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 32 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 346 SLBs with a coupon step up, 212 (61%) have a 25 bps coupon increase, 91 (26%) have less than a 25 bps increase, and 42 (12%) have more than a 25 bps increase.

3 A model for sustainability-linked bonds

In this section, 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 sustainability. Then, by assuming constant values for the interest rate, default frequency, recovery, and sustainability premium, we simplify the model.

3.1 A general model

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

We consider a low ESG factor to be favorable 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

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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 $C_1, ..., C_M$ as the cash flows in case the firm reaches the ESG target and additional cash flows $S_1^j, ..., S_{N_j}^j$ 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)):

$$\begin{aligned} P_0^{SLB} &= E_0^Q\Big[\sum_{i=1}^{M} C_i e^{-\int_0^{t_i^C}(r_s+\lambda_s-\omega_s)ds}\Big] + \sum_{j=1}^{K} E_0^Q\Big[1_{\{G_{T_j}^j > K_j\}} \sum_{i=1}^{N_j} S_i^j e^{-\int_0^{t_i^j}(r_s+\lambda_s-\omega_s)ds}\Big] \\ &\quad + E_0^Q\Big[\int_0^{t_M^C} \delta_u \lambda_u e^{-\int_0^u (r_s+\lambda_s-\omega_s)ds} du\Big] \\ &= \sum_{i=1}^{M} C_i D(r_0, \lambda_0, \omega_0, t_i^C) + \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j F(r_0, \lambda_0, \omega_0, G_0^j, K_j, t_i^j, T_j) + R(r_0, \lambda_0, \omega_0, \delta_0, t_M^C), \end{aligned}$$

where

$$D(r_0, \lambda_0, \omega_0, t) = E_0^Q\Big[e^{-\int_0^t (r_s+\lambda_s-\omega_s)ds}\Big], \tag{1}$$

$$F(r_0, \lambda_0, \omega_0, G_0, K, t, T) = E_0^Q\Big[1_{\{G_T > K\}} e^{-\int_0^t (r_s+\lambda_s-\omega_s)ds}\Big], \tag{2}$$

$$R(r_0, \lambda_0, \omega_0, \delta_0, t) = E_0^Q\Big[\int_0^t \delta_u \lambda_u e^{-\int_0^u (r_s+\lambda_s-\omega_s)ds} du\Big]. \tag{3}$$

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We decompose the price of the SLB into a standard bond component and an option:

$$P_0^{SLB} = P_0^{SUS} + O_0, \tag{4}$$

$$P_0^{SUS} = \sum_{i=1}^{M} C_i D(r_0, \lambda_0, \omega_0, t_i^C) + R(r_0, \lambda_0, \omega_0, \delta_0, t_M^C), \tag{5}$$

$$O_0 = \sum_{j=1}^{K} \sum_{i=1}^{N_j} S_i^j F(r_0, \lambda_0, \omega_0, G_0, K_j, t_i^j, T_j), \tag{6}$$

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:

$$P_0^o = \sum_{i=1}^{M} C_i D'(r_0, \lambda_0, t_i^C) + R'(r_0, \lambda_0, \delta_0, t_M^C) \tag{7}$$

Where:

$$D'(r_0, \lambda_0, t) = E_0^Q \left[e^{-\int_0^t (r_s + \lambda_s) ds} \right], \tag{8}$$

$$R'(r_0, \lambda_0, \delta_0, t) = E_0^Q \left[\int_0^t \delta_u \lambda_u e^{-\int_0^u (r_s + \lambda_s) ds} du \right]. \tag{9}$$

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

$$O_0^{UB} = \sum_{j=1}^{K} \sum_{i=1}^{N_j} S_i^j. \tag{10}$$

If the ESG factor(s) G are independent of the risk free rate r, default intensity λ and sustainium ω, equation (2) reduces to

$$F(r_0, \lambda_0, \omega_0, G_0, K, t, T) = E_0^Q \left[1_{\{G_T > K\}} \right] D(r_0, \lambda_0, \omega_0, t), \tag{11}$$

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

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is

$$ESGP_0 = \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_0^P\Big[1_{\{G_{T_j}>K\}}\Big] D(r_0,\lambda_0,\omega_0,t_i^j) - O_0 \quad (12)$$

$$= \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_0^P\Big[1_{\{G_{T_j}>K\}}\Big] D(r_0,\lambda_0,\omega_0,t_i^j) \quad (13)$$

$$-\sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_0^Q\Big[1_{\{G_{T_j}>K\}}\Big] D(r_0,\lambda_0,\omega_0,t_i^j) \quad (14)$$

$$= \sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j \Big(E_0^P\Big[1_{\{G_{T_j}>K\}}\Big] - E_0^Q\Big[1_{\{G_{T_j}>K\}}\Big]\Big) D(r_0,\lambda_0,\omega_0,t_i^j). \quad (15)$$

3.2 A tractable model

We now assume that the recovery rate, default intensity, sustainability premium, and riskfree rate are constant. In this case the expressions in equations (1)-(3) reduce to

$$D(r,\lambda,\omega,t) = e^{-(r+\lambda-\omega)t} \quad (16)$$

$$F(r,\lambda,\omega,G_0,K,t,T) = P^Q\Big[G_T > K\Big] e^{-(r+\lambda-\omega)t}, \quad (17)$$

$$R(r,\lambda,\omega,\delta,t) = \frac{\delta\lambda}{r+\lambda-\omega}\Big(1 - e^{-(r+\lambda-\omega)t}\Big). \quad (18)$$

If we furthermore assume that there is a single ESG factor G_t with target K at time T, the bond price simplifies to

$$P_0^{SLB} = \sum_{i=1}^{M} C_i D(r,\lambda,\omega,t_i^C) + \sum_{i=1}^{N} S_i F(r,\lambda,\omega,G_0,K,t_i,T) + R(r,\lambda,\omega,\delta,t_M^C) \quad (19)$$

and the ESG risk premium is

$$ESGP = \Big(E_0^P\Big[1_{\{G_T>K\}}\Big] - E_0^Q\Big[1_{\{G_T>K\}}\Big]\Big) \sum_{i=1}^{N} S_i D(r_0,\lambda_0,\omega_0,t_i). \quad (20)$$

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4 Data

In this section we describe the data and detail how we estimate the model in Section 3. Appendix A provides further details regarding cleaning of the data.

We restrict our sample of corporate bonds to fixed-rate bonds with a time-to-maturity of at least six months. We exclude callable bonds, except if 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. 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, August 25, 2022.

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 the two ordinary bonds that have available price and 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 4,676 transactions across 2,298 bond-days that appear to be 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

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remove the one present in the Propellant data set.

Table 4 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 very little transaction activity. Our data sample starts on September 10, 2019; the earliest issuance date of the SLBs in our 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 36 SLBs with 44 associated options[5], a combined issuance amount of 32.3 billion USD, and a total of 6,932 SLB bond-day observations spanning from September 8, 2020, to August 19, 2022. (Although the first SLB in our sample is issued on September 10, 2019, the first day an SLB passes the filter in Appendix A.3 is September 8, 2020.) The data sample contains 5.70% of the total number of SLBs in the Bloomberg database and 9.11% of the total issuance amount. We see in Table 3 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 6.89 years, a coupon of 1.53 and an issuance size of 1.062$ billion.

[5]There are two SLBs with three KPIs, four SLBs with two KPIs, and 30 SLBs with one KPI.

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5 Estimation

We estimate the model in Section 3.2 using a three-step procedure. For a given bond-day, 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. Then, we estimate the price of a bond with a sustainability premium but no option-linked cash flows and finally we estimate the ESG risk premium.

5.1 Ordinary bond

We compute the yield spread $s^o_{j,t}$ 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 $T_{L,t}$ (as described in Section 4):

$$s^o_{j,t} = \frac{T_{L,t} - T_{j,t}}{T_{L,t} - T_{S,t}} * s_{S,t} + \frac{T_{j,t} - T_{S,t}}{T_{L,t} - T_{S,t}} * s_{L,t}, \tag{21}$$

Where $s_{S,t}$ ($s_{L,t}$) is the yield spread of the short (long) maturity bond. If both ordinary bonds have either a 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:

$$s^o_{j,t} = \frac{T_{2,t} - T_{j,t}}{T_{2,t} - T_{1,t}} * s_{1,t} + \frac{T_{j,t} - T_{1,t}}{T_{2,t} - T_{1,t}} * s_{2,t}. \tag{22}$$

The yield-to-maturity of the ordinary bond is $y^o_{j,t} = s^o_{j,t} + r_{t,T_{j,t}}$ where $r_{t,T_{j,t}}$ is the $T_{j,t} - t$-year riskfree rate at time t.[6] We convert the discretely-compounded yield-to-maturity to a continuously-compounded yield-to-maturity $y^{o,cc}_{j,t}$ using the formula $y^{o,cc}_{j,t} = f_j * \ln(1 + \frac{y^o_{j,t}}{f_j})$, where f_j is the coupon frequency for bond j.

Using the notation in Section 3.1, the price of the ordinary synthetic bond is

$$\hat{P}^o_{j,t} = \sum_{i=1}^{M} C_i e^{-y^{o,cc}_{j,t} * t^C_i}, \tag{23}$$

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

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where C_i are the remaining cash flows of the SLB if the firm meets all ESG targets and t_i^C are the times until the cash flows are paid. The default intensity $\hat{\lambda}_{j,t}$ is estimated by solving equation (7) for λ:

$$\hat{P}^o_{j,t} = \sum_{i=1}^{M} C_i D(r_{t,T_{j,t}}, \lambda_{j,t}, 0, t_i^C) + R(r_{t,T_{j,t}}, \lambda_{j,t}, 0, \hat{\delta}, t_M^C) \tag{24}$$

where we use equations (16) and (18) and $\hat{\delta}$ is the historical recovery rate.[7] The SLB premium for bond j at time t, is $P^{observed}_{j,t} - \hat{P}^o_{j,t}$, where $P^{observed}_{j,t}$ is the observed bond price.

5.2 Sustainium

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 due to a convenience of holding the sustainium bonds.

Specifically, for SLB j at time t, with no option-linked cash flows and a yield spread of $s^{SUS}_{j,t}$, and a corresponding synthetic yield spread of an ordinary bond of $s^o_{j,t}$, we estimate the sustainium $\omega^{SUS}_{j,t}$ as:

$$\omega^{SUS}_{j,t} = s^o_{j,t} - s^{SUS}_{j,t}. \tag{25}$$

We estimate a common sustainium on day t by computing the average across all observations N_t^{SUS} at time t (we require $N_t^{SUS} \geq 3$),

$$\hat{\omega}_t = \frac{1}{N_t^{SUS}} \sum_{j=1}^{N_t^{SUS}} \omega^{SUS}_{j,t}. \tag{26}$$

The price of a sustainium bond is calculated as

$$\hat{P}^{SUS}_{j,t} = \sum_{i=1}^{M} C_i D(r_{t,T_{j,t}}, \hat{\lambda}_{j,t}, \hat{\omega}_t, t_i^C) + R(r_{t,T_{j,t}}, \hat{\lambda}_{j,t}, \hat{\omega}_t, \hat{\delta}, t_M^C) \tag{27}$$

[7] We use the average historical recovery rate between 1987-2021 of 34.8% from Moody's (2022) as our estimate of the recovery rate.

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

5.3 ESG risk premium

The implied option price is

$$\hat{O}_{j,t} = P^{observed}_{j,t} - \hat{P}^{SUS}_{j,t}. \tag{28}$$

To calculate the ESG premium we estimate $E^P_t\left[1_{\{G^j_{T_j} > K_j\}}\right]$ for a given ESG factor G^j with target K_j at time T_j. We assume that G^j follows a generalized Wiener process,

$$dG^j_t = \mu_j dt + \sigma_j dW_t \tag{29}$$

and at time t we observe historical observations of the factor at times $t^j_1 < t^j_2 < ... < t^j_k < t$ where $t^j_{i+1} - t^j_i$ is one year[8]. To estimate the parameters μ_j and σ_j, we note that $G^j_T - G^j_t \sim N\Big(\mu_j(T-t), \sigma^2_j(T-t)\Big)$ and estimate the linear regression

$$G^j_{t+1} - G^j_t = \beta + \epsilon_{t+1}, t = t^j_1, ..., t^j_{k-1}, \tag{30}$$

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

$$\hat{\mu}_j = \hat{\beta} \tag{31}$$

$$\hat{\sigma}_j = \hat{\xi}. \tag{32}$$

and it is straightforward to calculate $\hat{E}^P_t\left[1_{\{G^j_{T_j} > K_j\}}\right] = P_t\left[G^j_{T_j} > K_j | G^j_{t^j_k}\right]$.

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 a common time-t probability of missing the target as

$$E^{com}_t = \sum_{j=1}^{N} \hat{E}^P_t\left[1_{\{G^j_{T_j} > K_j\}}\right] \tag{33}$$

[8] 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 6 do not qualitatively change if we use an informational lag of zero or six months.

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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, $\tilde{E}_t^P\left[1_{\{G_{T_j}^j > K_j\}}\right]$, is then

$$\tilde{E}_t^P\left[1_{\{G_{T_j}^j > K_j\}}\right] = 0.25\hat{E}_t^P\left[1_{\{G_{T_j}^j > K_j\}}\right] + 0.75E_t^{com}. \tag{34}$$

To estimate the ESG premium, $ESGP_{j,t}$, we insert the empirical estimates $\hat{O}_{j,t}$ and $\tilde{E}_t^P\left[1_{\{G_{T_j}^j > K_j\}}\right]$ into equation (12).

6 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 what impacts SLB prices and ESG risk premiums.

6.1 Liquidity

The ease with which a corporate bond is traded affects corporate bond prices[9], and we therefore compare the liquidity of SLBs with 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 there is no clear relation between SLB liquidity and the liquidity of ordinary bonds. On one hand, the Amihud measure is higher for ordinary bonds, suggesting that SLBs are more liquid, but on the other hand trade size is higher and the lower IRC estimate of average roundtrip cost of 16.2bps for ordinary bonds indicate higher liquidity for ordinary bonds. The differences are not statistically significant, with the exception of

[9]See Friewald, Jankowitsch, and Subrahmanyam (2012), Bao, Pan, and Wang (2011), Dick-Nielsen, Feldhütter, and Lando (2012), Feldhütter (2012) and others.

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IRC, 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 0.739 years while it is 5.864 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 (2.438 pr. day vs 1.080 pr. day for ordinary bonds) and that the trading volume is higher ($2.039m pr. day vs $0.868m pr. day for ordinary bonds). The differences in age and trading activity 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]

6.2 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, Fitzgibbons, and Pomorski (2021), Pastor, Stambaugh, and Taylor (2021), Feldhütter and Pedersen (2022) and others), similar to the premium found for green bonds. However, ESG investors' willingness to pay a premium for SLBs may be different than for green bonds as well as similar sustainable securities such as social bonds. If ESG investors' non-pecuniary benefits accrue solely through ownership as experimental evidence in Bonnefon et al. (2022) suggests, the sustainium may be zero. In contrast, if investors are concerned with the actual impact of their portfolio decisions as in Oehmke and Opp (2022) and Moisson (2022), the sustainium might be significantly positive. We estimate

[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.

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a daily sustainium using 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 can be attributed to the ESG label itself.

Table 7 Panel A shows the average sustainium ('Raw sustainium'), calculated as described in Section 5.2 for the time period from October 20, 2021, to August 19, 2022. The sustainium is 3.93bps and statistically significant, implying that investors are willing to pay a premium for the ESG-label of SLBs. The panel also displays the average daily green bond premium – the greenium – from Feldhütter and Pedersen (2022) from September 8, 2020, to August 19, 2022.[11] The greenium is of similar magnitude as the sustainium, 3.57bps. The correlation between the sustainium and greenium is 79% for the overlapping period. Thus, the greenium and sustainium have similar magnitudes and time series variations, suggesting that both ownership and impact investing are important for ESG investors.

Although the average sustainium is statistically highly significant, there are two sources of noise that plague the time series variation. First, the matching of non-SLB and SLB bonds is imperfect. Second, there are not many SLB bonds, particularly early in the sample, where the bond's coupon is not contingent on the company meeting a sustainability goal.[12] We decrease the noise in the time series variation of the sustainium by regressing the raw sustainium on the estimate of the greenium from Feldhütter and Pedersen (2022) and use the predicted values from the regression. This approach has the additional benefit that we can extend our estimate of the sustainium to the early part of the sample where there are no observations of the raw sustainium.

Panel B in Table 7 shows the regression results. Without a constant the slope regression is close to one at 1.16 and the pseudo-R^2 is 0.44. Including a constant leads to a negative constant and a larger slope coefficient of 2.39. A non-negative constant is economically more reasonable, so we use specification (1) to estimate the smoothed sustainium. Panel C shows

[11]Feldhütter and Pedersen (2022) estimate the greenium as the yield difference between non-green and green sovereign bonds matched perfectly on coupon and maturity. Their greenium estimate is easy to calculate and less noisy than earlier estimates in the literature due to the perfect matching.

[12]Both our estimates of sustainium and the SLB premium contain the first type of noise. The second source of noise is significantly more prevalent in our daily estimates of the sustainium compared to our daily estimates of the SLB premium because there are significantly fewer SLBs with carbon offset/donations than there are SLBs with sustainability-linked coupons.

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that the smoothed sustainium is 4.16bps, close to the raw sustainium. Specification (3) and (4) shows that the smoothed sustainium is of similar magnitude and significantly positive when we control for bond liquidity.

Figure 3 plots the time series of the sustainium. The sustainium is always positive and is increasing in the first half of the sample and decreases towards the end of the sample, showing the investor-demand for SLBs has a significant impact on the pricing of the bonds.

6.3 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. The average probability is 27% and quite low for both reducing green house gasses (GHG), at 22%, and non-GHG targets, at 36%. 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 (0.95) without (with) liquidity controls. Thus investors take into account penalty sizes when pricing SLBs and higher penalties translate into higher bond

[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).

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prices as basic financial theory implies. In a regression of the SLB premium on the probability of missing the target, the regression coefficient is negative but statistically insignificant, both with and without liquidity controls. The probability estimates are based on relatively few data points and it is perhaps not surprising that they are measured with significant estimation error and thus the regression coefficient is statistically insignificant.

6.4 Are SLBs mispriced?

The existing literature on SLB 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 and SLBs are overpriced. In contrast Berrada, Engelhardt, Gibson, and Krueger (2022) find that SLBs trade at lower prices than ordinary bonds on average, i.e. SLBs are underpriced on average.[15]

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

$$Mispricing_t = \frac{P_t^{SLB} - P_t^o}{O_t^{UB}} \tag{35}$$

where P_t^{SLB} is the SLB price, P_t^o is the price of an ordinary non-ESG bond given in equation (7), and O_t^{UB} is the upper bound in equation (10). If the mispricing measure is greater than one, the SLB 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.

We test if there is mispricing in Table 8. The first row in the table shows that the average SLB premium is significantly higher than zero and the second row that the premium is significantly below the upper bound. The SLB premium reduces when controlling for bond liquidity as the second column shows but is still between the lower and upper bound

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

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on average.

Figure 4 shows the mispricing measure over time. The figure shows that there are short periods in the early part of the sample where the mispricing measure is higher than one, but the overpricing is short-lived and statistically insignificant. In the last part of the sample, the mispricing measure is slighly smaller than zero, but again the distance to the mispricing bound of zero is statistically insignificant. Overall, we find no evidence that SLBs are mispriced.

6.5 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 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.[16]

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 5.3. Table 10 Panel A shows the average ESG premium and we see that the point estimates are negative, although statistically insignificant, consistent with the embedded option being a hedge against climate risk. We have a relatively short data sample for estimating risk premiums and this may be why the estimates are statistically insignificant.

Turning to the time series variation of the risk premium, Panel B shows that the risk

[16]See Giglio, Kelly, and Stroebel (2021) for an extensive review.

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premium is higher when risk premiums in general – as measured through the VIX – are higher. There is no significant relation between the ESG risk premium and ESG rating, but a higher credit rating is related to a more negative ESG premium. Seltzer, Starks, and Zhu (2022) find that firms with a higher level of carbon emissions exhibit lower credit ratings, so it may be that there is a negative risk premium for carbon intensive firms and a positive risk premium for low-emitting firms.[17]

7 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 include credit risk, investor preferences for sustainable securities, the likelihood that the firm will fulfill the target and the penalty size in order to analyze 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

[17] The regression coefficient on credit rating between -0.34 and -0.26 is economically large relative to the unconditional average of -0.20 and this may be due to the fact that most of the bond-days have a rating of BBB, in total 82.5%, so the identification is mainly due to those bonds and the linear relation might not extend to low or high ratings.

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the ESG option embedded in SLBs is strongly related to the size of the penalty. Overall, our empirical results indicate no mispricing.

We also find that firms set targets that are easy to reach: the average probability of meeting the target in our sample period is 73%. Furthermore, we find that investors are willing to accept a 4–7bps 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, but statistically insignificant, providing some preliminary evidence that SLBs can be used as financial hedges against ESG risk.

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A 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 prioritise 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, and Tradition. 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 1,000). 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.

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Table A1 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 (Section 6), we first discard all SLB bond-days where the absolute SLB premium, $|P_{j,t}^{observed} - \hat{P_{j,t}}|$ (see Section 5.1), is above 5. Then, we 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 or if the bond has no option-linked cash flows. Finally, we discard a bond-day if we are not able to calculate all the necessary parts of our theoretical model laid out in Section 3: The price of an ordinary bond ($P_{j,t}$), the price of a sustainium bond ($P_{j,t}^{SUS}$), and the physical option value $\sum_{j=1}^{K}\sum_{i=1}^{N_j} S_i^j E_t^P \left[1_{\{G_{T_j}>K\}}\right] D(r_{t,T}, \lambda_t, \omega_t, t_i^j)$.

Cleaning Step	# of Transactions Removed	# of Transactions Remaining
Uncleaned Data	-	138,584
Step 1	986	137,598
Step 2	23,606	113,992
Step 3	1,771	112,221
Step 4	3,432	108,789
Step 5	68	108,721
Step 6	-	108,721

Table A1: 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 describtion of each step can be found in the text.

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	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	

Table 1: *General Mill's greenhouse gas emissions.* Historical data (2018-2020) for scope 1 and scope 2 greenhouse gas emissions by General Mills, provided in the second party opinion (SPO) by ISS.

Panel A: KPI Type

	# of SLBs Issued	Issuance Amount (USD Billions)
GHG (Greenhouse Gas)	317	180.6
Other	157	66.8
ESG Rating	125	36.7
Renewables	89	32.7
Missing Info	59	18.2
Diversity	42	19.6
Multiple KPIs	199	95.8

Panel B: Penalty Type

	# of SLBs Issued	Issuance Amount (USD Billions)
Coupon Step Up	346	194.2
Coupon Step Up/Down	136	39.7
Cash/Redemption	65	24.4
Carbon Offset/Donation	32	6.2
Missing Info	31	13.3
Complex	15	5
Step Down	7	0.5

Panel C: Coupon Step Up Penalty

	# of SLBs Issued	Issuance Amount (USD Billions)
= 25 BPS	212	141.5
< 25 BPS	91	29.7
> 25 BPS	42	22.6
Missing Info	1	0.4

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 199 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 August, 2022.

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Panel A: KPI Type

	# of SLBs Issued	Issuance Amount (USD Billions)
GHG (Greenhouse Gas)	29	25.0
Other	8	6.3
ESG Rating	0	0.0
Renewables	5	4.3
Missing Info	0	0
Diversity	2	1.9
Multiple KPIs	6	3.7

Panel B: Penalty Type

	# of SLBs Issued	Issuance Amount (USD Billions)
Coupon Step Up	39	34.1
Coupon Step Up/Down	0	0.0
Cash/Redemption	5	3.3
Carbon Offset/Donation	0	0.0
Missing Info	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	27.4
< 25 BPS	10	5.8
> 25 BPS	1	0.9
No Information	0	0.0

Table 3: *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.

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Panel A: Data Sources Overview

	Bonds	Transactions	Bond-Days
Bloomberg	384	-	188,280
TRACE	89	157,439	20,477
Propellant	226	76,236	23,773

Panel B: Regions

	EU	US	AS	Other
Bloomberg	94,331	24,460	55,968	13,521
TRACE	6,842	12,258	451	926
Propellant	21,339	1,269	360	805

Panel C: Propellant Venues

	Bonds	Transactions	Bond-Days	Volume (Millions)
Bloomberg	221	24,259	13,776	20,329.69
Marketaxess	206	19,931	10,382	13,367.32
Tradeweb	205	31,019	13,331	21,599.06
LSE	144	838	693	347.65
Tradeecho	56	156	124	192.04
Tradition	10	33	13	55.35

Table 4: *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 August 25, 2022.

	Mean	Std	Min	p1	p25	p50	p75	p99	Max
Age (In Years)	0.74	0.56	0.00	0.01	0.27	0.60	1.10	2.15	2.31
TTM (In Years)	6.89	2.54	2.46	2.60	4.72	6.72	9.20	12.04	12.51
Coupon	1.53	1.29	0.00	0.00	0.38	1.38	2.45	4.62	4.75
Yield-to-Maturity	2.23	1.60	-0.37	-0.24	0.89	2.20	3.36	5.73	9.80
Yield Spread	1.04	0.72	-0.48	0.11	0.46	0.89	1.46	3.26	7.76
Issuance (USD Millions)	1,062	443	166	166	837	1,007	1,250	2,161	2,161

Table 5: *Summary statistics for SLB sample.* The distribution of the age, time-to-maturity, coupon, yield-to-maturity, yield spread, and issuance amount for all SLB bond-day observations included in our sample.

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	SLBs	Ordinary bonds	Difference	N
Amihud	0.023	0.025	-0.002	3,373
			(0.005)	
IRC	0.199	0.162	0.038*	1,768
			(0.022)	
Trade Size (Millions)	0.956	0.980	-0.024	3,896
			(0.220)	
Trade Count	2.438	1.080	1.358***	6,932
			(0.415)	
Volume (Millions)	2.039	0.868	1.170***	6,932
			(0.285)	
Age	0.739	5.864	-5.125***	6,932
			(1.030)	

Table 6: *Bond liquidity.* At the bond-day level we calculate the Amihud measure, IRT 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 equations (21)-(22)), 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.

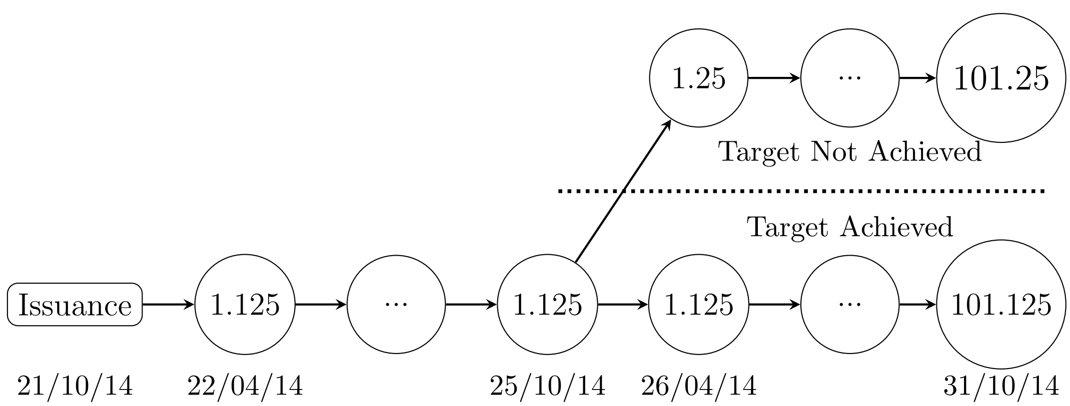

Figure 1: *SLB issued by General Mills in 2021.* This figure illustrates the possible cash flows of the SLB issued by General Mills on October 14, 2021. The bond has a fixed semi-annual coupon of 1.125% and if General Mills fails to achieve a target reduction of 21% in scope 1 and scope 2 greenhouse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

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Panel A: Average raw sustainium and greenium				
Raw sustainium	3.93***			
	(0.64)			
	[206]			
Greenium	3.57***			
	(0.18)			
	[509]			
Panel B: Regression of sustainium on greenium				
	(1)	(2)	(3)	(4)
Constant		-4.89***		-5.67
		(1.34)		(4.25)
Greenium	1.16***	2.39***	2.08***	2.43***
	(0.10)	(0.37)	(0.28)	(0.40)
Liquidity controls	No	No	Yes	Yes
Pseudo-R^2	0.44	0.62	0.60	0.62
N	202	202	202	202
Panel C: Average sustainium				
Sustainium	4.16***	3.67***	7.42***	3.02***
	(0.20)	(0.42)	(0.36)	(0.42)
	[509]	[509]	[509]	[509]

Table 7: *Yield sustainium.* Panel A shows the average yield sustainium and greenium. 'Raw sustainium' is the average sustainium for the period October 20, 2021 - August 19, 2022, calculated as the average yield difference between non-SLB bonds and SLB-bonds where there are no bond cash flow effects of the issuing firm reaching the target (as detailed in Section 5.2). 'Greenium' is the estimated green bond premium for the period September 8, 2020 - August 19, 2022 from Feldhütter and Pedersen (2022). There are a total of 1,688 bond-days and 13 unique SLBs with no option-linked cash flows in the sample used to calculate the raw sustainium on 206 days. The liquidity controls are $\frac{1}{N_t^{SUS}}\sum_{j=1}^{N_t^{SUS}}\left(\log(1+L^o_{i,j,t})-\log(1+L^{SUS}_{i,j,t}\right), i=1,..,3$ 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. 'Sustainium' in Panel C is the predicted value from the regressions in Panel B where 'Greenium' (and potentially a constant) is used as single predictor. Newey-West standard error with a lag of 12 are in parentheses and number of observations in square brackets, while pseudo-R^2 is calculated as $1-\frac{\frac{1}{T}\sum_{i=1}^{T}(y_t-\hat{y}_t)^2}{\frac{1}{T}\sum_{i=1}^{T}(y_t-\overline{y}_t)^2}$. *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 level, respectively.

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SLB premium	0.68***	0.20
	(0.25)	(0.24)
UB - SLB premium	0.37*	0.85***
	(0.22)	(0.21)
Liquidity controls	No	Yes
N	6,932	6,932

Table 8: *Mispricing*. This table shows if the SLB premium is significantly different from the upper of the option value as well as zero. There are 6,932 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: Probability of missing target						
	All	GHG	non-GHG			
	0.27***	0.22***	0.36***			
	(0.02)	(0.02)	(0.03)			
	[6,932]	[4,272]	[2,660]			
Panel B: Determinants of SLB premium						
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-0.43	0.91**	-0.32	-0.62**	0.49**	-0.45
	(0.30)	(0.37)	(0.41)	(0.29)	(0.25)	(0.37)
Penalty size	1.05***		1.04***	0.95**		0.92**
	(0.37)		(0.37)	(0.38)		(0.39)
Prob. missing target		-0.85	-0.33		-1.18	-0.57
		(1.15)	(1.01)		(1.13)	(1.04)
Liquidity controls	No	No	No	Yes	Yes	Yes
R^2	0.17	0.01	0.17	0.19	0.08	0.20
N	6,932	6,932	6,932	6,932	6,932	6,932

Table 9: *SLB premium determinants*. Panel A shows the average estimated probability of meeting the sustainability 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.

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Panel A: ESG risk premium						
	All	GHG	non-GHG			
	-0.20	-0.11	-0.36			
	(0.24)	(0.23)	(0.52)			
	[6,932]	[4,272]	[2,660]			
Panel B: Determinants of the ESG risk premium						
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-1.01	1.98***	1.05	-0.70	3.62***	2.67***
	(0.63)	(0.49)	(0.82)	(0.60)	(0.58)	(0.79)
VIX	0.03*		0.04*	0.04**		0.04**
	(0.02)		(0.02)	(0.02)		(0.02)
ESG rating		-0.01	-0.01		-0.11	-0.11
		(0.11)	(0.11)		(0.11)	(0.11)
Credit rating		-0.26***	-0.26***		-0.34***	-0.34***
		(0.06)	(0.07)		(0.06)	(0.06)
Liquidity controls	No	No	No	Yes	Yes	Yes
R^2	0.02	0.08	0.10	0.08	0.23	0.24
N	6,932	6,932	6,932	6,932	6,932	6,932

Table 10: *ESG risk premium*. Panel A shows the average ESG risk premium given in equation (12). '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.

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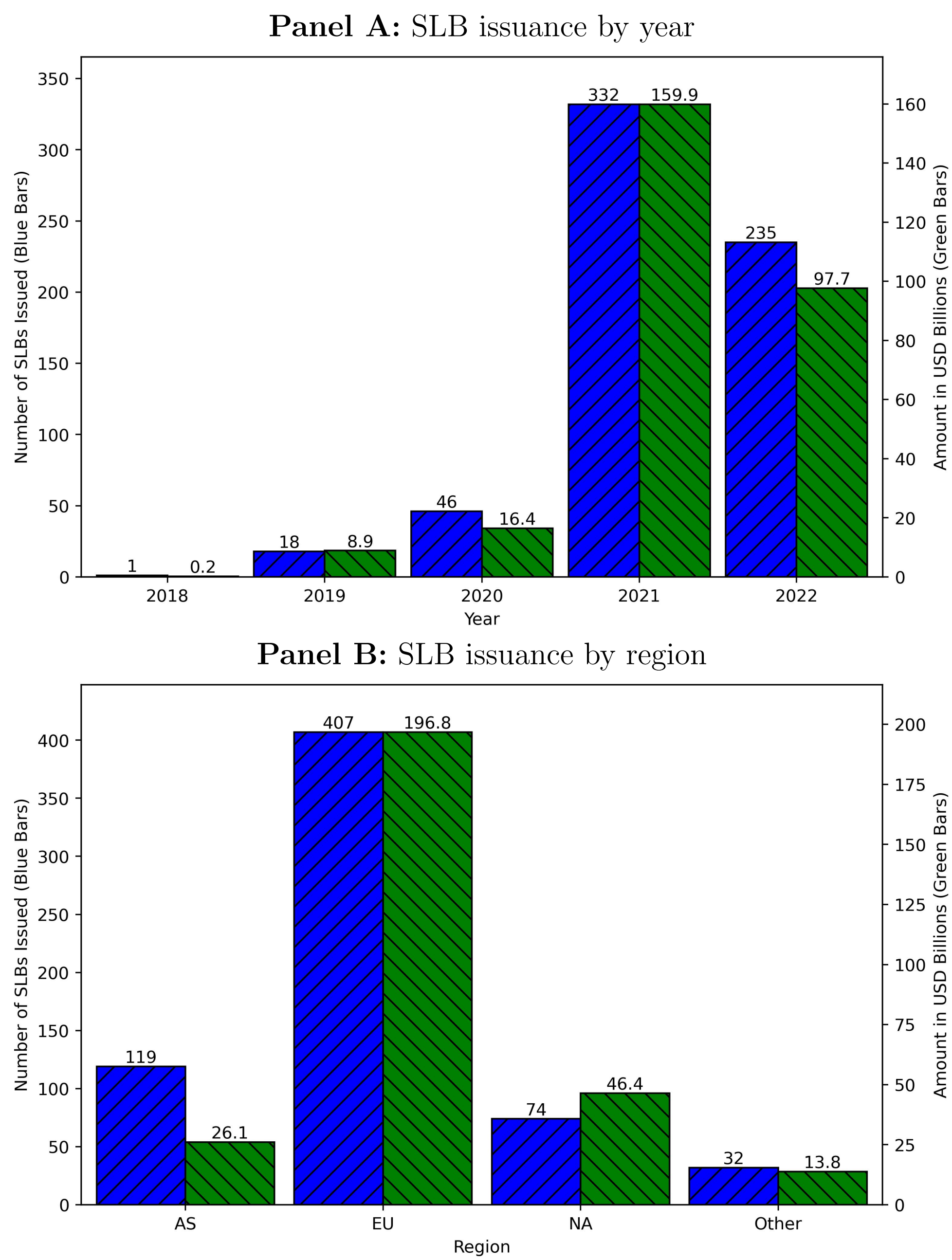

Figure 2: This figure shows the growth of the SLB market since its inception in 2018. The left (blue) bars show the number of SLBs issued each year while the right (green) bars show the notional amount of SLBs issued (in USD billions). The data is from Bloomberg and includes all bonds that have a sustainability-linked indicator equal to 1. The data for 2022 ends August 25.

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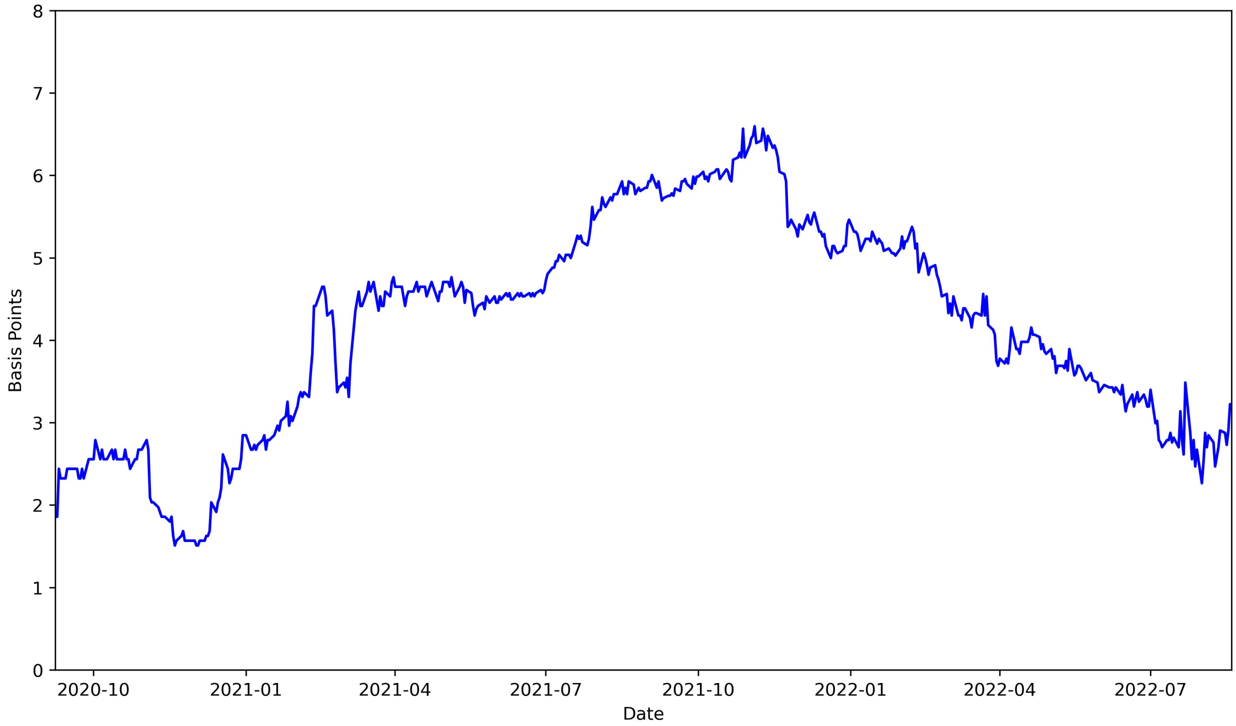

Figure 3: *Yield sustainium.* A raw sustainium is estimated by calculating the yield difference between the yield of non-SLBs and the yield on SLBs with the particular feature that their coupon is not tied to the issuing firm reaching a sustainability target (instead the firm denotes money to sustainability-linked causes). The sustainium is then computed as the predicted value from a regression of the sustainium on the greenium estimate from Feldhütter and Pedersen (2022).

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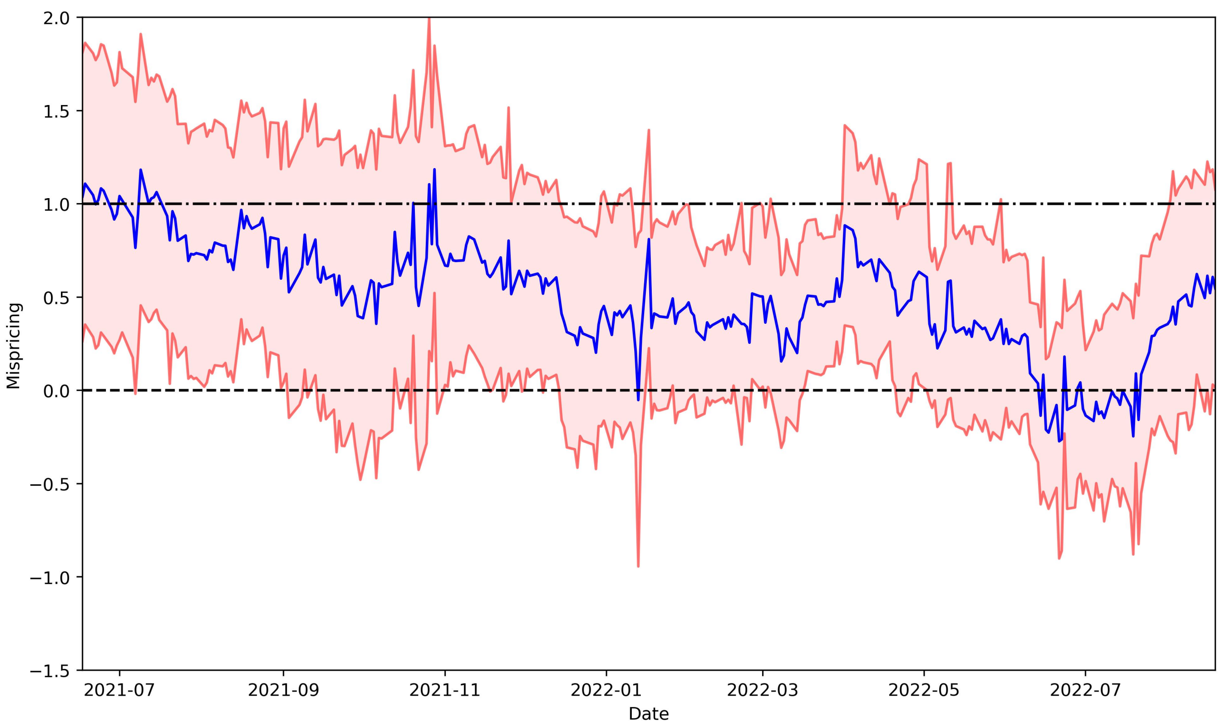

Figure 4: *Mispricing*. The figure shows the time series variation of the mispricing measure for the SLB premium. On each day in the sample where we have at least ten observations we compute the mispricing measure as the average SLB premium on that day divided by the average upper bound on the same day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

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