Sovereign green bonds: Reducing climate capital costs in emerging markets

Vedanshi Nevatia[1]

Abstract: Using sovereign green bonds as benchmark securities, this study investigates regional variations in the cost of climate debt between developmentally segregated economies. It also assesses the viability of sovereign green bonds as risk-mitigating public instruments for climate finance through the estimation of "*greenium*." To achieve this, the study employs the coarsened exact matching technique to identify the closest counterfactual bond. This research is particularly timely, given the urgent need for direct government participation in green finance and the growing share of sovereign-issued bonds in the green bond market. The findings demonstrate that the green labeling of sovereign bonds significantly reduces climate capital costs in emerging markets by lowering perceived risk and informational asymmetry, especially for riskier countries, speculative-grade bonds, and during periods of financial volatility. Surprisingly, the study finds a positive premium for sovereign green bonds in advanced economies, thereby narrowing the regional cost of debt gap.

JEL Codes: Q01, Q56, Q58, G12, H63, F34

Keywords: Green bonds, sovereign green bonds, *greenium*, climate finance, climate policy country risk mitigation, energy transition, emerging markets, sustainable investing, impact investment, fixed-income securities, coarsened exact matching, sustainable development goals (SDGs), Environmental, Social and Governance (ESG) investing

[1] PhD Candidate, Department of Economics, Colorado State University, Fort Collins, CO 80523-1172, United States. Email: Vedanshi.nevatia@colostate.edu

1. Introduction

Rapid transformation the global energy sector toward predominantly renewable and clean technologies requires substantial investment, particularly in developing countries where the impacts of climate change are more severe (Adom, 2024). However, volatile macroeconomic conditions, a lack of business confidence, and opacity in regulatory frameworks pose significant barriers to accessing financing for low-carbon projects in these regions (Ameli et al. 2021; Bilir, Chor, and Manova 2019; Egli, Steffen, and Schmidt 2019; Ragosa and Warren 2019). Although international investment in renewable energy nearly tripled after 2015, most of this growth was concentrated in developed countries. Emerging economies, which require approximately USD 1.7 trillion annually for renewable energy investments, attracted only USD 544 billion in 2022 (UNCTAD 2022)[2]. This disparity illustrates the "climate investment trap" in emerging economies, where underdeveloped financial markets lead to high country-risk premiums, increasing the cost of debt, slowing climate mitigation investments, and exacerbating climate impacts (Ameli et al. 2021).

In response to these challenges, the past decade has seen the emergence and exponential growth of the sovereign *green* bond market (Ando et al. 2023; Doronzo, Siracusa, and Antonelli 2021; G. Cheng, Ehlers, and Packer 2022; R. Cheng, Gupta, and Rajan 2023; Xiao, n.d.). A sovereign green bond is a fixed-income debt instrument issued by the government to finance verified environmental projects. Since their first issuance by France and Poland in 2017, the cumulative amount issued through sovereign green bonds has grown to 366 billion USD globally as of 2023 (see Figure 1). As part of governments' green fiscal policy, sovereign green bonds are an innovative tool that can potentially finance mitigation costs, increase welfare, and promote intra- and intergenerational equity through fair climate transition (Doronzo et al., 2021). For emerging economies, sovereign green bonds can not only advance national environmental agendas but also reduce the perceived risk in their financial sector by reducing informational asymmetry through improved reporting standards (R. Cheng et al., 2023). The evidence also suggests that sovereign green bonds have positive spillover effects on the issuance size and pricing of green bonds in the private sector (Xiao, n.d.). Given their pivotal role, it is essential to study the pricing dynamics of sovereign green bonds to assess their viability as a climate financing tool, particularly in emerging markets.

Building on the distinctive characteristics of sovereign bonds as benchmark macro securities (Dittmar & Yuan, 2008; Presbitero et al., 2016), this research analyzes the green finance risk-mitigating properties of

[2] Retrieved from UNCTAD World Investment Report 2022: https://unctad.org/system/files/official-document/wir2022_en.pdf. Last access: 2 August 2024.

sovereign green bonds in developed and emerging markets. This study is the first to systematically estimate regional differences in the cost of climate debt, measured through sovereign green bond yields. Additionally, it provides an estimate of the cost of debt associated with sovereign green, social, and sustainability (GSS) bonds, a rapidly growing category not labeled explicitly green. The findings aim to offer policy insights into the utility of sovereign green bonds as instruments for financing climate transitions in diverse economic contexts.

This study specifically investigates the presence, magnitude, and volatility of sovereign "*greenium*" in the secondary market—a lower yield premium on green bonds, which reflects their climate financing potential (Arat et al. 2023; Baker et al. 2022; Banga 2019; Dorfleitner, Utz, and Zhang 2022; Fatica, Panzica, and Rancan 2021; Grishunin et al. 2023; Leitao, Ferreira, and Santibanez-Gonzalez 2021; Löffler, Petreski, and Stephan 2021; Zerbib 2019). G*reenium* is mostly attributed to the nonpecuniary incentive for investors to invest in climate instruments and transparency in the use of proceeds of such bonds (MacAskill et al., 2021). The presence of *greenium* indicates a lower cost of capital for the issuer and a higher probability of investment opportunity due to high investor demand driving up green bond prices (or driving down yields). While the existence of *greenium* has been debated (Baker et al., 2022; Zerbib, 2019), studies consistently show its presence in green bonds issued by government entities, particularly in the secondary market (Bachelet et al., 2019). However, research on sovereign *greenium* remains limited (Ando et al., 2023).

Furthermore, the study addresses the regional variation in green bond pricing dynamics (Doronzo et al., 2021; Ivashkovskaya & Mikhaylova, 2020), a gap attributed to the scarcity and heterogeneity of firm-level data, policies, and taxonomies in emerging economies (Grishunin et al., 2023). Most green bond studies analyze either global issuances or limit them to only the largest markets, such as the U.S., Europe or China. This research fills this gap by utilizing the homogeneity and transparency of sovereign bond data to explore regional variations in *greenium.*

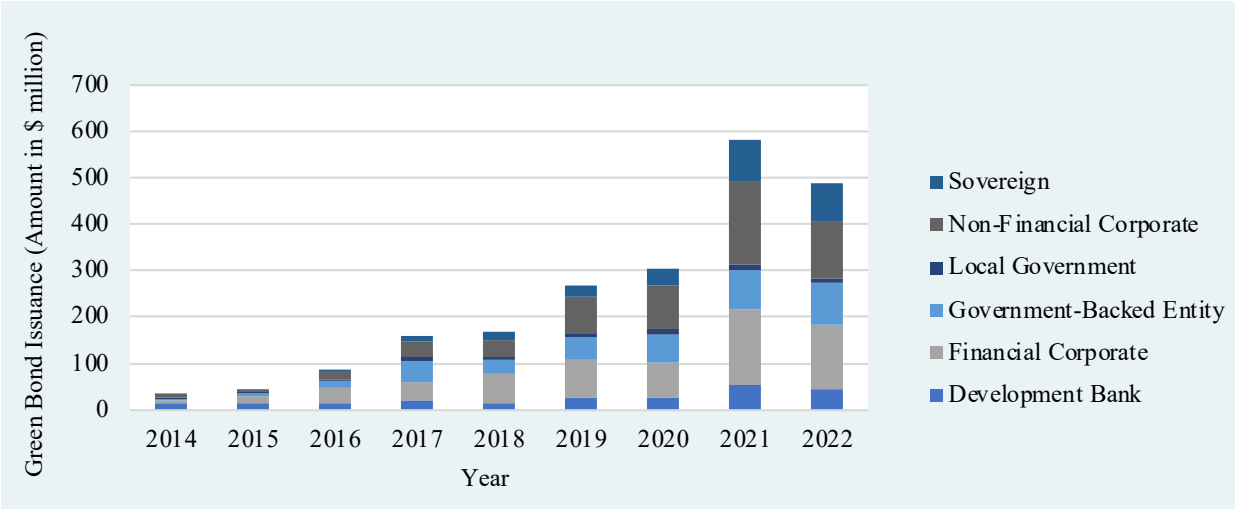


Figure 1: Growth of green bond issuance by issuer type. Retrieved from Climate Bonds Initiative. https://www.climatebonds.net/market/data/.

The study utilizes data from Bloomberg and identifies sovereign sustainability bonds issued between 2017 and 2023 across 42 countries. Given the caveat that any 2 bonds, even from the same issuer, may not be perfectly comparable, the distinguishing feature of a sovereign bond is that it is not affected by microeconomic firm-level heterogeneity. Leveraging this simplification, the study employs coarsened exact matching (CEM) to identify the closest possible counterfactuals for each green bond analyzed. It then uses a two-way fixed effects model to draw causal inferences on the effect of green labeling on sovereign bond yields at the global and regional levels. Finally, it uses a fixed effects panel data model to establish a direct relationship between country risk and sovereign *greenium.*

The study finds a significant sovereign *greenium* of -10.2 basis points for emerging economies, contrasted by a positive and significant yield premium of 42.5 basis points for sovereign green bonds in advanced economies. These findings have substantial policy implications: green-labeling of sovereign bonds reduces climate capital costs in emerging markets by lowering perceived risk, especially for speculative-grade bonds and during periods of financial volatility. The results are further strengthened by a significant positive premium on nonlabelled GSS bonds in emerging economies, indicating the importance of reporting standards. Conversely, this risk mitigation through green labeling does not extend to advanced economies, where conventional bonds might act as safe havens.

This research makes several contributions to the literature: it is one of the few studies investigating regional and temporal variations in sovereign *greenium,* the first to compare yield differentials between sovereign GSSs and conventional bonds, and the first to use CEMs to form precise bond pairs for estimating average treatment effects for sovereign green bonds. Additionally, it explores how sovereign green bonds mitigate country risk, identifying the groups most likely to benefit from their issuance.

The remainder of this paper is structured as follows: Section 2 outlines the theoretical framework underpinning the study. Section 3 provides a comprehensive overview of green bonds, sovereign green and sustainability bonds and the literature on *greenium*. Sections 4 and 5 detail the data and methodology. Section 6 presents the model estimation results and various specifications. Sections 7 and 8 conclude with a discussion of the findings, policy implications, and avenues for future research.

2. Theoretical Framework

Several notable studies have made theoretical predictions about how environmental concerns influence asset pricing and investment (Baker et al. 2022; Fama and French 2007; Heinkel, Kraus, and Zechner 2001; Idzorek, Kaplan, and Ibbotson 2023; Oehmke and Opp 2024; Pastor, Stambaugh, and Taylor 2021; Pedersen, Fitzgibbons, and Pomorski 2021). The highly acclaimed Fama and French (2007) model uses a modified version of the capital asset pricing model (CAPM) to analyze the effect of taste-based investor biases on equity pricing. In this framework, a security's expected return accounts for the traditional CAPM beta for systematic risk and a second term that captures the agents' tastes for an asset's environmental attributes. However, the above models are designed for equity pricing.

The standard exponential affine function to determine bond prices posits that the logarithm of bond prices can be determined by macroeconomic risk factors and bond-specific characteristics (Dittmar & Yuan, 2008). This study therefore combines the standard function with the taste-based CAPM model to include additional bond price determinants: the use of proceeds indicating investors' preferences for environmental assets, and green labeling to demonstrate bias towards symmetrical reporting standards. Figure 2 demonstrates that the sovereign bond price is a function of a set of macroeconomic risk factors, and bond characteristics, including greenness of the asset. However, evidence shows that country risk is a significant determinant of bond characteristics (Damodaran, 2012). The three hypotheses developed in Section 3 therefore test for the direction and magnitude of corresponding factors, by controlling for other confounding variables and also studies the synergies between country risk and greenness of the bond.

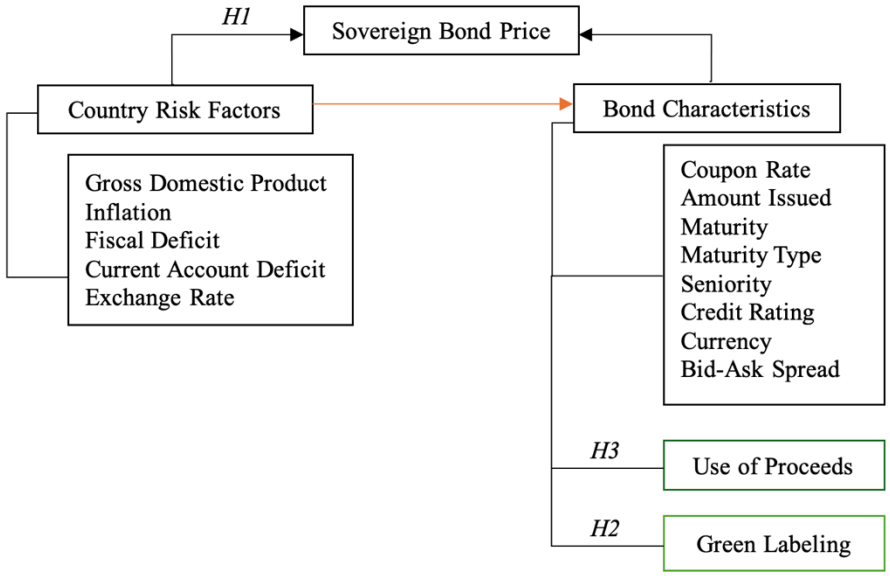


Figure 2: Theoretical Framework

3. Background and Literature Review

3.1. Green Bonds and the Case for Sovereign Green Bonds

Green bonds, or bonds explicitly labeled "green," are fixed-income securities designated to finance projects that address climate and environmental challenges. These typically include investments in clean and renewable energy, energy efficiency, green infrastructure, or electrified transportation[3]. The first green bond was issued in 2007 by the World Bank in cooperation with the Swedish National Bank[3]. Since then, the market has grown significantly, from USD 11 billion in 2013 to USD 2.15 trillion in 2023 (see Figure 1). Demands for green bonds consistently surpass supply in both primary markets, where new bonds are issued, and secondary markets, where issued bonds are freely traded (MacAskill et al., 2021).

Although green bonds still represent a small percentage of the cumulative bond market (S&P Global)[4], they account for 58% of the total sustainability bonds issued (CBI 2022)[5]. Green bonds can be issued by various entities, including governments, municipalities, financial and nonfinancial corporations, and development banks. As of 2023, approximately 67% of green bond issuance originates from advanced economies, with approximately 50% issued by public corporations. European issuers have been the most prevalent, followed by US, Chinese, and supranational issuers. European issuers dominate the market,

[3] Retrieved from Climate Bonds Database. https://www.climatebonds.net/market/explaining-green-bonds. Last access: 2 August 2024.
[4] Retrieved from S&P Global, "Measuring the Impact of Green Bonds". https://www.spglobal.com/esg/insights/blog/measuring-the-impact-of-green-bonds. Last access: 2 August 2024.
[5] Retrieved from ICMA Group, "Green Bonds Principles", June 2023. https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles-June-2022-060623.pdf. Last access: 2 August 2024.

followed by those in the U.S., China, and supranational entities. The average issuance size of green bonds is generally smaller than that of conventional bonds, with approximately 88% of deals being less than USD 500 million. Short- to medium-term tenors, typically under five years, are most common.

Currently, the certification of green bonds lacks a universal global regulatory framework. Instead, it is generally aligned with the Green Bond Principles (GBPs) published by the International Capital Markets Association (ICMA)[5] in 2014. The ICMA also designates third-party verifiers for the green labeling and documentation of bond proceeds, including CBI, Bloomberg, Dealogic, and Environmental Finance[6]. Of these, only CBI and Bloomberg require alignment with GBP principles to be listed as a green bond, and CBI does not provide information on bond pricing dynamics. This study, therefore, leverages Bloomberg's well-documented green bond database for replicability. However, the process of green bond certification entails substantial administrative and transaction costs. Additionally, since issuers are not mandated to adhere to GBP guidelines, approximately 20% of corporate green bonds are self-labeled as green without external review, contributing to the ambiguity in corporate green bond pricing (MacAskill et al., 2021). This issue, compounded by underdeveloped capital bond markets with limited private participation, remains a significant barrier to the growth of green bonds in emerging economies (Banga, 2019; Jain et al., 2022; Magale, 2021; Mankata et al., 2022).

Sovereign bonds hold a unique position in that they can be treated as benchmark securities for the country under analysis (Dittmar & Yuan, 2008), in that they embody only macroeconomic country risk, not firm-specific microeconomic risk. Hence, combinations of sovereign bond rates and equity premiums are generally used as proxies for country risk measurement (Ameli et al., 2021; Gautam et al., n.d.). Sovereign bonds are also found to have strong positive spillover effects on corporate bond markets (Bevilaqua, Hale, and Tallman 2020; Presbitero et al. 2016). Evidence shows that their issuance promotes market completeness and price informativeness in emerging economy financial markets (Dittmar & Yuan, 2008).

It can therefore be reasonably assumed that sovereign green bond issuance would perform a similar function. A recent study by (Xiao, n.d.) revealed that sustainable corporate green bond issuance increased, with evidence of greater liquidity and reduced yield spreads following sovereign green issuance. Sovereign green bonds have also facilitated the development of standardized verification standards for the green bond market (Xiao, n.d.). In fact, all emerging economies, apart from India and Nigeria, issued

[6] Retrieved from ICMA Group, "Summary of Green Bond Database Providers", May 2017. https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Green-Bond-Databases-Summary-Document-190617.pdf. Last access: 2 August 2024.

other green bonds only after the first sovereign green issuance. G. Cheng, Ehlers, and Packer (2022) note that *all* sovereign issuers are endorsed by at least one, and often multiple, third-party verifiers.

Owing to this increased transparency, sovereign green bonds can issue larger amounts with longer maturities, thereby reducing refinancing risk (G. Cheng et al., 2022). The public sector accounts for 80% of bonds with the longest tenors (20 years and above), with sovereigns representing 39%. The financial literature indicates that issue size is positively related to the coupon rate, credit rating, and financial health of issuers, with internationally denominated bonds being larger (Steckel and Jakob 2018). Given that climate mitigation is a global goal, sovereign green issuances can promote international financial pooling through established channels because of their risk-bearing capacity (Oman, n.d.; Zettelmeyer, n.d.). Doronzo, Siracusa, and Antonelli (2021) reported that Poland's sovereign green bond issuance attracted new green investors, accounting for 61% of its investor base. Therefore, sovereign green bonds can facilitate a smoother transition into the bond market and are better positioned to manage green certification costs.

Given that sovereigns act as benchmark securities, they are useful tools to estimate a country's cost of debt and draw regional comparisons. The same applies to sovereign green bonds. However, in structurally underdeveloped markets, the elevated cost of debt financing may also extend to climate-related debt instruments, potentially reflecting broader market inefficiencies. Hence, the following hypothesis is proposed:

H1: There is a systematic difference in the yields of sovereign green bonds between advanced and emerging markets.

3.2. The *Greenium*

The *"greenium"* or green bond premium refers to the yield differential at which green bonds are priced compared with comparable traditional bonds. Generally, expressed in basis points (bps), *greenium* is calculated as the spread between the yield of a green bond (GB) and a matched conventional bond (CB) yield, as given by equation (1):

$$Greenium = (Yield_{GB} - Yield_{CB}) \times 100 \qquad (1)$$

The presence of *greenium* across primary and secondary markets and among various issuers has been a heavily researched topic in the green bond literature, with inconclusive results. Some studies suggest a small positive, albeit significant, green bond premium, whereas others report a negative or negligible premium (Agliardi and Agliardi 2021; Ando et al. 2023; Bachelet, Becchetti, and Manfredonia 2019;

Baker et al. 2022; Fatica, Panzica, and Rancan 2021; Gianfrate and Peri 2019; Grishunin et al. 2023; Hachenberg and Schiereck 2018; Hu et al. 2024; Ivashkovskaya and Mikhaylova 2020; Karpf and Mandel 2018; Liaw 2020; Löffler, Petreski, and Stephan 2021; Nanayakkara and Colombage 2019; Tang et al. 2023; Zerbib 2019). The variability in results is often attributed to differences in dependent variables, matching methods, analytical and econometric models, and the scope of analysis, ranging from corporate issuers to municipalities and from individual countries to regional groupings.

For example, Zerbib (2019) uses a synthetic matched conventional bond to analyze 110 green bonds in the secondary market, finding a low negative premium of -2 bps. Gianfrate and Peri (2019) employ propensity score matching (PSM) and identify an 18-bps premium among 121 European green bonds, with corporate issuers benefiting the most. Grishunin et al. (2023), on the other hand, reported a greenium of approximately -3 bps in the European market. Baker et al. (2022), utilizing the Fama and French (2007) technique, and Karpf and Mandel (2018), using the synthetic bond matching method, study the pricing of municipal green bonds in the U.S. and both report a negative *greenium*, although the latter attributes it observable bond characteristics. Tang et al. (2023) analyzes global corporate green bonds and finds a positive stock market reaction to green bond issuance but no statistically significant premium. Fatica, Panzica, and Rancan (2021) do not find a premium for financial institutions. (Hu et al., 2024) find that greenium is attributed to corporate issuers' greenness in the Chinese market.

Löffler, Petreski, and Stephan (2021) are the only ones to use coarsened exact matching (CEM) to test for the yield premium, finding a negative and statistically significant *greenium* in both primary and secondary markets. Nanayakkara and Colombage (2019) apply the natural logarithm of OAS to analyze yield differences between daily yields of conventional bonds and green bonds in a sample of 125 bonds from 2016–2017 and find that green bonds traded at a premium of 63 bps compared with comparable corporate bonds. MacAskill et al. (2021) provide a meta-analysis concluding that green premiums are identified in 56% of primary and 70% of secondary market studies, particularly for publicly issued, investment-grade, certified bonds with stronger reporting procedures. Recently, it has been suggested that *greenium*, especially in the private sector, may gradually disappear as the market matures (Kanamura 2020, Duguid 2022[7])

Studies on the determinants of green premia identify four key areas: (1) investors' preference for environmentally sound instruments; (2) greater liquidity of green bonds; (3) government incentives and tax breaks; and (4) compliance with GBP and the assignment of green certificates (Hyun, Park, and Tian

[7] Retrieved from Financial Times, "Rising green bond issuance erodes premiums", July 18, 2022. https://www.ft.com/content/32dbf37c-8ff5-436b-88f3-9873fc864a7b. Last access: 2 August 2024.

2021; 2023; Ivashkovskaya and Mikhaylova 2020; MacAskill et al. 2021). Flammer (2021) find stronger positive abnormal stock price reactions to the announcement of green bonds certified by independent third parties and first-time issuers. Among the few regional studies, Caramichael and Rapp (2024) find that while green bond governance significantly influences *greenium*, the credibility of the underlying projects does not have a substantial effect. Instead, *greenium* is unevenly distributed among large, investment-grade issuers, primarily in the banking sector and developed economies. (Dorfleitner et al., 2022; Fatica et al., 2021; Kapraun et al., 2021) demonstrate that external certification of "greenness" is a crucial driver of green bond premia in the U.S. and international bond markets. Ivashkovskaya and Mikhaylova (2020) use OAS spread to show that *greenium* is significant and more pronounced in developed economies (27.2 bps) than in emerging economies (18.3 bps). The authors emphasize the heteroskedasticity of the market and the policy and goodwill of the issuer when studying emerging economies. Moreover, they find that *greenium* is related to a higher level of liquidity associated with green bonds. Fatica, Panzica, and Rancan (2021) also find significant *greenium* in developed country primary markets for all green bond types but a positive premium of 20.61 bps for emerging economies.

The literature on sovereign green bonds is growing, although most studies explore different market aspects rather than *greenium* (G. Cheng et al., 2022; R. Cheng et al., 2023; Doronzo et al., 2021; Oman, n.d.). (Xiao, n.d.) makes significant contributions by empirically demonstrating the spillover effects of sovereign green bond issuance on private *greenium.* They show that sovereign issuance not only increases the size and maturity of private green bonds but also solidifies green bond verification standards within a country. To date, only one preliminary study by Ando et al. (2023) has examined the yield dynamics of the sovereign green market. This study constructs a synthetic bond, as in (Zerbib, 2019), to compare Z-spreads between sovereign green bonds and conventional bonds, finding significant *greenium* for both advanced (4 bps) and emerging (11 bps) economies. However, the study is limited in scope, as it excludes bonds issued after mid-2022 and therefore considers only 23 matched sovereign, green-labeled bonds out of the 113 issued. Moreover, critical factors such as bond credit ratings, market tickers and varying macroeconomic risk measures are not accounted for in the study (see Section 5). This study seeks to address this research gap.

3.3. Twin Bonds Case Study

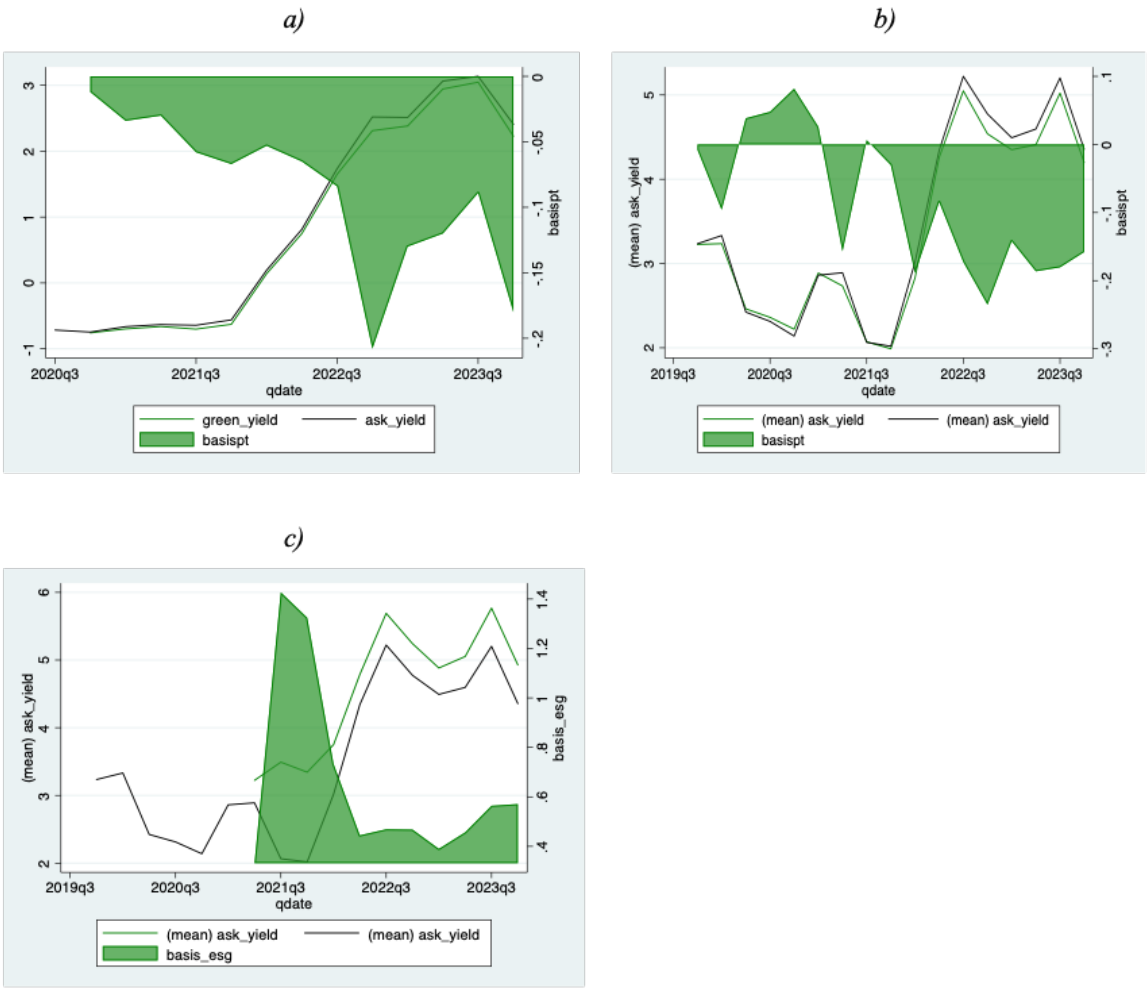


Figure 3: *Greenium* for German twin bonds (a) and Chile twin bonds (b) and yield premium for Chile's non-labeled sustainability bond over the matched conventional bond.

To establish a benchmark *greenium* for government securities in the Euro green finance market, Germany issued four pairs of twin "bunds" in 2020, comprising one green-labeled bond and one conventional bond (German Finance Agency, 2022). These paired bonds were designed with identical maturity dates and coupon rates but differed in issuance size. Figure 3a illustrates the yields and *greenium* for one such twin bond pair maturing in 2030. The green bond consistently traded at a *greenium* of -5--20 bps (Figure 2a) in the secondary market. However, the conventional bond was issued with a size of €30 billion, whereas the green bond was issued with a size of €6 billion, potentially leading the *greenium* to be biased downwards. The established financial literature suggests that the issuance size is positively related to the bond yield to compensate investors for potential liquidity losses (Chiesa & Barua, 2019).

In this study, each sovereign green bond is matched with its nearest conventional counterpart, controlling for issuance size. An example from Chile is illustrated in Figure 3b for a green bond pair. In 2018, the

Chilean Ministry of Finance (MoF) issued its first sovereign green bonds to promote sustainable finance and development toward a low-carbon economy. The bond is found to be trading at a lower yield than matched conventional bond in the secondary market, with the *greenium* reaching -25 bps over time.

Based on the reviewed literature and the twin-bond case study, following hypothesis is proposed:

*H2: The difference between the yields of sovereign green bonds and their conventional counterparts (*i.e.*, greenium) is negative, significant, and more pronounced for emerging economies.*

Bonds that are not explicitly labeled green but are allocated to sustainable (green and social) activities are categorized as GSS bonds by CBI (and environmental, social, governance (ESG) bonds by Bloomberg). Sovereign issuers contributed 20 billion USD in 2022 to this category. Sovereign issuers contributed 20 billion USD to this category in 2022. Because GSS bonds are not subject to stringent financial documentation and labeling costs, they can be more easily issued by countries with less developed financial institutions (CBI 2022) [8]. For example, the Philippines has historically relied heavily on developed economies for climate finance and technology. In 2021, the country established a sustainable financing framework and issued its first sustainability bond in 2022 (CBI 2022)[8]. The academic literature on social and sustainability bonds is more limited, primarily due to fewer issuances. Emerging evidence suggests either a nonexistent or minimal sustainability premium (Torricelli & Pellati, 2022).

An intriguing case was provided by a pair of sovereign bonds issued by Chile: a green-labeled bond (ISIN: US168863DL94) and a non-labeled GSS bond (ISIN: XS2327851874). Although not intentionally issued under the twin-bond criteria, both bonds share similar characteristics, differing only in the amount issued (USD denominated, A- rated, 3.5% coupon rate, issued in 2021 with a 30-year maturity). The project details for both mention “Solar Wind Hydro Digital energy and energy efficiency BREEAM or other building and energy efficient infrastructure Electric Public Rail Sustainable infrastructure for clean and/or drinking water”, but the nongreen GSS bond also includes health care (Bloomberg). Over the 11 quarters since issuance, the yields of the two bonds have varied within 5 bps of each other, with no consistent appearance of *greenium* (see Appendix, Table A1). However, the issuance size of the green bond is USD 2.3 billion, whereas that of the GSS bond is USD 1.5 billion. This example indicates the possibility that green labeling sustainability loans *allow* countries to issue larger amounts because of their reporting standards, provided that 100% of their proceeds are used only for climate purposes. Figure 3c here illustrates the case of a Chilean sovereign non-labeled GSS bond paired with a conventional bond. In

[8] Retrieved from Climate Bonds Initiative, “Sustainable debt, Global state of the market”. https://www.climatebonds.net/files/reports/cbi_sotm_2022_03e.pdf. Last access: 2 August 2024

contrast to Figure 2b, the GSS bond is selling at a yield premium reaching a maximum of 140 bps. Therefore, the following hypothesis is proposed:

H3: Yields of sovereign GSS bonds that are not labeled green are substantially different from those of green-labeled bonds.

4. Data

To conduct the analysis, I constructed a novel dataset of 2,150 sovereign bond yields spanning 42 countries, beginning with the first global issuance of sovereign green bonds by Poland in January 2017. The data for each country start from the date its first sovereign green or GSS bond was issued, resulting in an unbalanced panel. The quarterly frequency of bond yields was selected because it offers greater granularity and sensitivity to macroeconomic factors and market-risk perceptions (Gopinath et al., n.d.). This approach also efficiently captures seasonal volatility, particularly during the timeframe considered, which includes significant events such as the COVID-19 pandemic and the Ukraine War. While many financial studies use bond-day panels to gauge microeconomic costs and benefits for issuers and investors through *greenium* (Baker et al. 2022; Karpf and Mandel 2018), this study aims to offer macroeconomic policy prescriptions for developed and emerging economies over the long run. As such, daily frequencies may capture excessive idiosyncratic volatilities arising more from market fluctuations than from broad trends, making quarterly data more appropriate for controlling country-level risk factors, which are typically available no more frequently than quarterly data (Gopinath et al., n.d.).

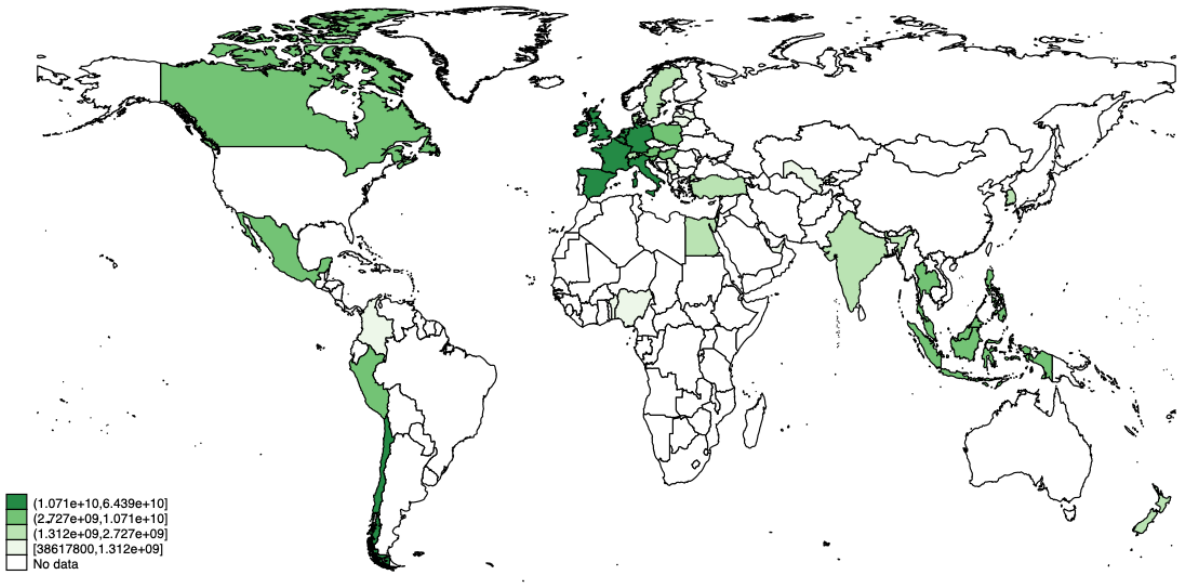


Figure 4: Representation of the amount issued (in USD) through sovereign green bonds by country.

Countries are categorized into advanced economies (AEs) and emerging and developing economies (EMDEs) according to the IMF World Economic Outlook Classification (April 2023)[9]. Figure 4 presents a map of the amount issued through sovereign green bonds across countries. presents a map of the amount issued through sovereign green bonds across countries. While AEs generally issue higher amounts (indicative of healthier credit ratings), there is fair representation of EMDEs among issuers. For each country, the dataset includes quarterly time series data on bond-ask yields to maturity, as well as other bond-level and country-level characteristics. The following sections discuss the data sources, the steps taken to create the dataset, and the summary statistics of the study variables.

The dataset was created by first extracting the entire sample of 171 sovereign GSS bonds indexed by Bloomberg as of December 31, 2023, using a 'Green/Sustainability' filter on the 'Use of Proceeds' criteria for bonds classified as sovereign under the Bloomberg Industry Classification Standard (BICS) Level 2. Of these, 113 bonds were identified as green-labeled by complying with the GBP guidelines and third-party verification. Note that all the GSS bonds are issued primarily for projects related to renewable energy deployment or energy efficiency, and no green bonds are outside the GSS category[10]; however, only 65.45% of the GSS bonds, mostly from developed economies, are labeled with green. This finding indicates that green labeling has substantial administrative and transaction costs, which, to be feasible, must not surpass the benefit from the country's *greenium,* if any. This is because green labeling involves substantial administrative and transaction costs, which must not surpass the benefits from the country's *greenium*, if any. Eleven countries, including Benin, Luxembourg, Mexico, Malaysia, Slovenia, Spain, Uzbekistan, Latvia, Peru, the UAE, and Cyprus, have issued only GSS bonds. All other countries have issued a combination of both categories of bonds.

Next, data were extracted for all conventional sovereign bonds (CBs) for those countries that have issued at least one GSS bond. Unlike GSS bonds, 96% of conventional sovereign bond issuances do not explicitly state the purpose of their issuance, highlighting the nonmandatory nature of reporting the use of proceeds. Bond and issuer characteristics, including the currency and country of the issuer, amount issued, coupon rate, maturity, maturity type, seniority, and S&P rating, were then collected from Bloomberg. Bonds without information on the coupon rate or maturity date were excluded.[11] Additionally, the maturity type was restricted to "At Maturity" (where bonds are only repaid with interest after the full life cycle and cannot be redeemed by the issuer in between) to avoid the need for option-adjusted spreads (OASs) to account for embedded options (Ivashkovskaya and Mikhaylova, 2020; Nanayakkara and

[9]IMF World Economic Outlook 2023 classification of countries conforms with the World Bank Classification by Income-level 2022-23, except for Hungary, which is classified as High-Income by the latter.
[10] See Appendix Table A2 for a detailed description of the use of proceeds and projects for which each GSS bond is issued.
[11] Fiji and Isle of Man have been excluded from analysis due to lack of availability of credible bond as well as country-level data.

Colombage, 2019). Since only four sovereign green bonds had other options, they were removed from the analysis. The final sample comprises 36,797 unbalanced nested country–bond–quarter panels, with data ranging from January 1, 2017, to December 31, 2023. A visual representation of the data stratification is presented in Figure 5.

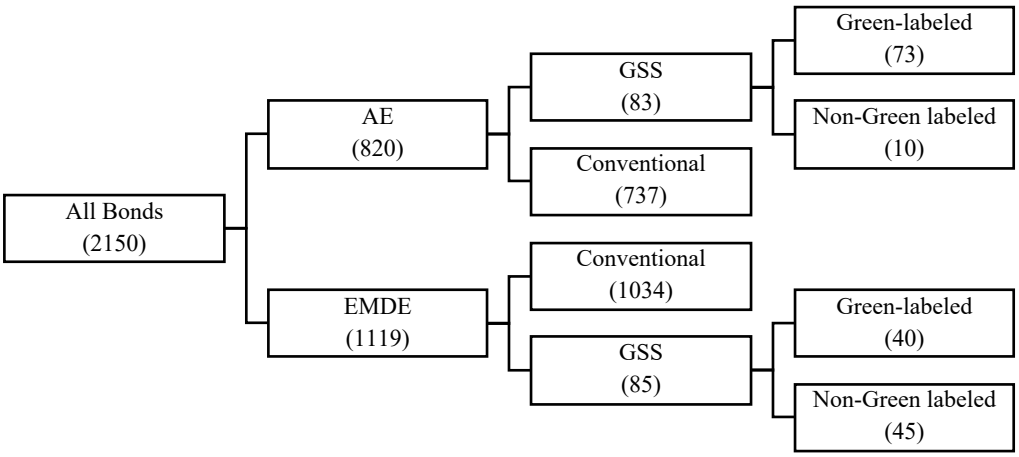


Figure 5: Data stratification according to region, project and bond-labeling.

Data for country-specific time-varying macroeconomic control variables were collected from various sources, including the International Financial Statistics (IFS) by the IMF, the Organization for Economic Cooperation and Development (OECD), and the World Bank Open Data (WBOD). Specifically, real GDP, the consumer price index (CPI), the trade balance, the fiscal deficit, and public debt were extracted from the IFS, and the financial development (FD) index was extracted from the IMF. The real effective exchange rate (REER) was obtained from Bruegel[12], which provides the most comprehensive and updated database on exchange rates and includes information for all countries in the dataset. Together, these variables control for internal and external country risk determinants (G. Cheng, Ehlers, and Packer, 2022).

There is considerable observed variability and skewness in the sample groups, particularly between issuing currencies and credit ratings. Figure 6 presents an overview of currency composition across the AE and EMDE economies, grouped by green label[13]. Stronger currencies such as the Euro (EUR), U.S. dollar (USD), and Japanese yen (JPY) still dominate both markets, but bonds issued in local currencies are increasingly represented in EMDE countries, especially for nongreen bonds in the South Asian region.

[12] Retrieved from Darvas, Zsolt (2021) 'Timely measurement of real effective exchange rates', Working Paper 2021/15, Bruegel, 23 December 2021. https://www.bruegel.org/sites/default/files/private/wp_attachments/WP-2021-15-231221-1.pdf. Last access: 2 August 2024

[13] GSS bonds not labeled green are combined with conventional in Figure 5, as no significant difference is observed across those groups.

Several emerging economies, such as India, Nigeria, and Colombia, have issued sovereign bonds exclusively in local currencies. The literature has established that yields can vary significantly on the basis of the risk perceptions and volatility associated with international versus local currencies, particularly for green bonds (Nanayakkara & Colombage, 2019; Zerbib, 2019). For example, while the average yield at issuance ranges between 1% and 2% for EUR-, USD-, and JPY-denominated bonds, it ranges from 7% to 8% for Indian rupees (INRs) and Indonesian rupiahs and up to 13.5% for Nigerian naira (NGNs), all of which have at least one green-labeled bond issued.

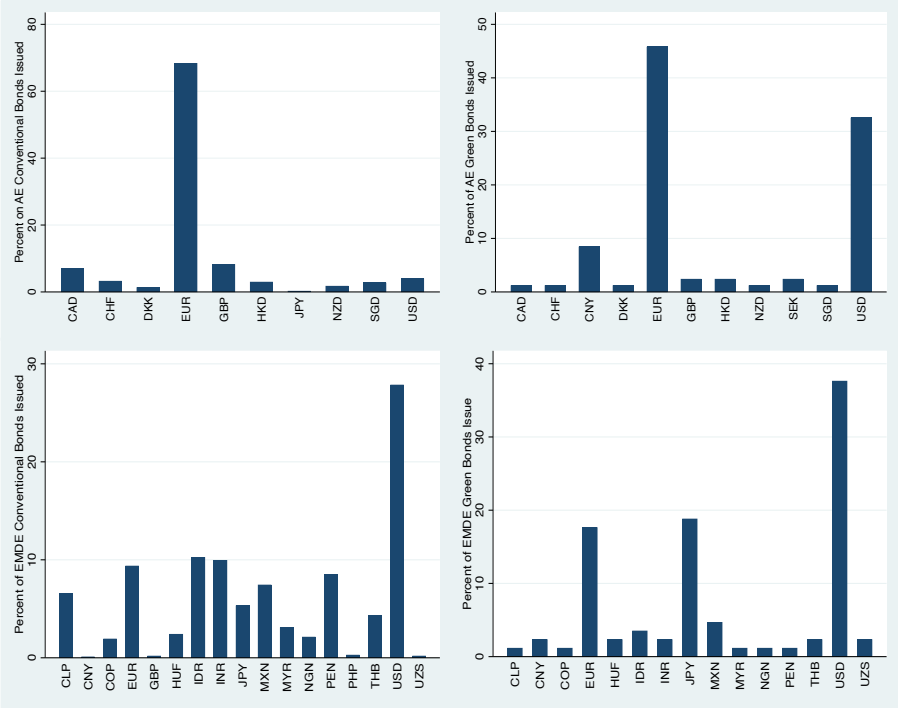


Figure 6: Distribution of sovereign green and conventional bonds by currency, for advanced (AE) and emerging economies (EMDE).

Figure 7 illustrates the Standard & Poor's (S&P) credit rating composition of bonds. Following the S&P credit system, bonds rated AAA-BBB are assigned investment grade, whereas those rated BB-B- and N/A or NR (not rated) are assigned speculative grade. Approximately 95% of bonds from AEs are rated as investment grade, whereas 50--55% for emerging economies (excluding the NR rated). However, the investment grade composition for the latter group increases significantly for both GSS and green-labeled bonds. While only 4.93% of CBs have a high A- rating, 23.53% and 17.95% of GSSs and green bonds, respectively, command the same rating, indicating the possibility of *greenium* stemming from higher credibility assigned to clean energy project-based debts in EMDEs. The observations of the mean coupon rate for each S&P rating category show an upward trend from the investment grade (NR to BBB-) to the speculative grade (BB+ to N/A). The data indicate that a higher credit rating is associated with longer

bond maturities, and a larger amount issued generally allows for lower liquidity and coupon rates, which range from 1.45% for investment-grade bonds to 9.125% for speculative-grade bonds.

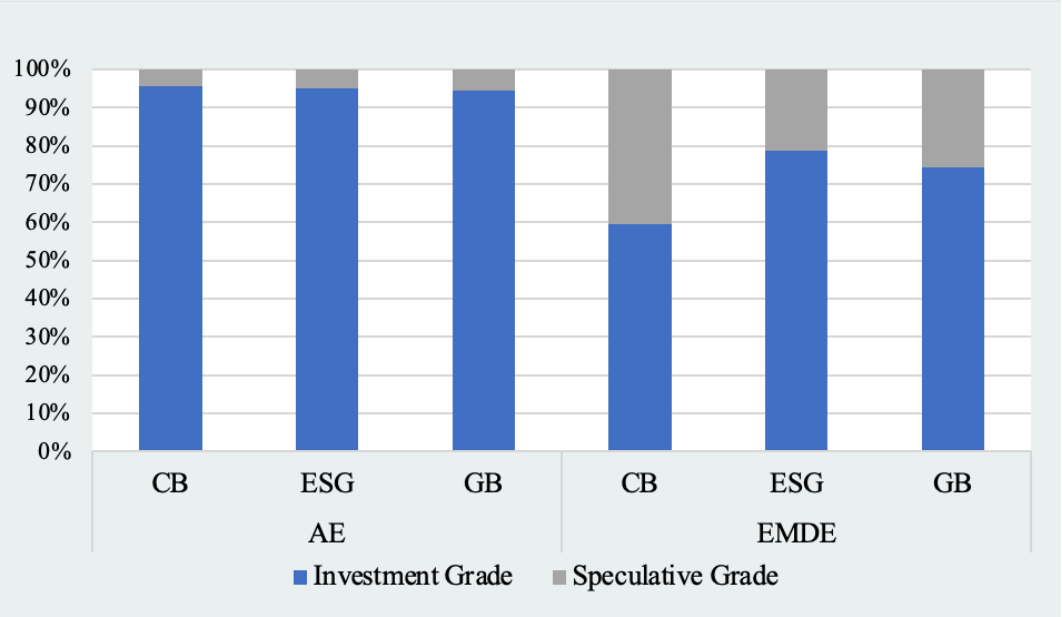


Figure 7: Distribution of bonds conventional (CB), non-labeled ESG (Environmental, Social and Government) bonds and Green Bonds (GB) by credit rating, for advanced (AE) and emerging (EMDE) economies. Following Standard & Poor's credit rating standards, bonds rated between AAA and BBB- are assigned to the investment grade bond group, whereas bonds rated between BB+ to B- and N/A or NR (not rated) are assigned to the speculative grade bond group.

Table 1 presents the statistics for the main bond identifications, including the coupon rate, maturity, and amount issued, highlighting structural differences across bond tranches and country groups. EMDE conventional bonds have the highest interest rates, which gradually decrease for GSS and green-labeled bonds. AE-issued bonds still have lower rates, indicating skewed risk perceptions toward financially developed economies, but rates increase slightly with the greenness of the bonds. In the case of both bond maturity and amount issued, higher values signify greater exposure to volatility and illiquidity and are generally associated with higher interest rates to compensate for expected future risks. Since AEs benefit from country-risk hedging, they can issue higher amounts and longer-maturity bonds at comparatively lower interest rates (Gopinath et al., n.d.).

Table 1. Summary statistics.

	All countries			Advanced economies			Emerging and developing economies		
	Conventional bond	GSS Bonds (unlabeled)	Green bonds	Conventional bond	GSS Bonds (unlabeled)	Green bonds	Conventional bond	GSS Bonds (unlabeled)	Green bonds
Coupon Rate (%)									
Mean	4.23	3.29	2.81	2.12	2.38	2.36	5.74	4.17	3.65
SD	3.21	2.73	2.21	1.80	1.72	1.60	3.14	3.22	2.87
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.73
Max	16.29	14.50	14.50	9.41	6.50	5.25	16.29	14.50	14.50

Maturity (years)									
Mean	16.18	12.29	11.36	16.84	11.39	11.72	15.71	13.17	10.68
SD	12.32	9.63	9.26	13.21	9.23	9.77	11.63	9.99	8.29
Min	0.50	0.25	0.25	0.50	0.25	0.25	0.50	1.75	2.00
Max	100.75	50.25	50.00	100.00	50.00	50.00	100.75	50.25	30.75
Amount Issued (USD millions)									
Mean	9340	2580	3290	17900	4160	4600	3330	1050	877
SD	12900	4960	5900	15800	6650	6980	4490	1050	647
Min	0	22.20	38.60	44.10	81.50	81.50	0	22.20	38.60
Max	87200	35400	35400	87200	35400	35400	26600	6780	2500

Note: Here, GSS stands for green, social and sustainability bonds.

5. Methods

5.1. Correcting for selection bias

The data description indicates a statistical imbalance between the treatment and control groups for the country-level and bond-level analyses. Without a matching technique amount, the maturity, currency and credit rating of a bond might drive the assignment of the label, region and yield. Therefore, selection bias hinders causal inference (Löffler et al., 2021). To resolve this concern, a matching method is applied to achieve comparability across three categories: AE-EMDE, green-labeled versus non-green-labeled and GSS versus non-GSS.

5.1.1. Propensity score matching

In previous studies assessing green bond market performance, various matching approaches have been utilized to compare pairs of securities that are similar across all attributes, except for one differing characteristic targeted for the analysis (Gianfrate and Peri 2019; Löffler, Petreski, and Stephan 2021; Zerbib 2019). The choice of technique originates from theories of statistical inference working on the axiom that the data are generated by simple random sampling, where each population unit has the same probability of selection (Abadie & Imbens, 2011). The key goal of matching is to prune observations from the data so that the remaining data have a better balance between the treated and control groups. Unfortunately, studies employing some form of approximate matching estimators (e.g., nearest neighbor matching, radius matching, kernel matching, and propensity score matching (PSM)) routinely violate this balancing goal to draw causal inference (S. Iacus et al., 2009), which guarantees a reduction in variance (precision) but not imbalance within groups (comparability).

A correctly specified PSM model can achieve both covariate balance and variance minimization. Table 2 presents the results of the logit regression used to estimate a PSM variation. The following control variables are employed: the coupon rate, the log of the amount issued, the maturity of the bond, the currency, the credit rating, the country of issue, and the quarter of the year under analysis. To avoid

multicollinearity issues with the country variable, currency is divided into 2 groups: domestic and international. Credit ratings are also stratified into two groups: investment-grade bonds and speculative-grade bonds. The estimated coefficients for the quarter dummy variables indicate an increasing likelihood of green bond issuance over time relative to the base period of 2017Q1. The probability of issuing green bonds in international currencies and with investment-grade ratings is significantly greater. Furthermore, the results demonstrate that, compared with conventional bonds, green bonds tend to have significantly lower coupon rates and issuance amounts.

Table 2. Logit estimation of green bonds (treatment=1).
Estimated coefficients of selected variables.

	Green Bond=1	SD
Constant	2.043	(1.261)
Coupon	-0.310***	(0.0315)
Log of Amount Issued	-0.331***	(0.0279)
Maturity	-0.00451	(0.00441)
Domestic currency [a]	-4.952***	(0.293)
Investment grade [b]	5.045***	(0.432)
2017Q2 [c]	-0.0272	(1.456)
2017Q3	-0.0543	(1.455)
2017Q4	-0.0808	(1.454)
2018Q1	1.001	(1.193)
2018Q2	1.281	(1.155)
2018Q3	1.237	(1.155)
2018Q4	1.472	(1.131)
2019Q1	1.990*	(1.088)
2019Q2	2.276**	(1.071)
2019Q3	2.251**	(1.071)
2019Q4	2.227**	(1.071)
2020Q1	2.319**	(1.066)
2020Q2	2.338**	(1.060)
2020Q3	2.395**	(1.057)
2020Q4	2.495**	(1.054)
2021Q1	2.549**	(1.051)
2021Q2	2.600**	(1.048)
2021Q3	2.668**	(1.046)
2021Q4	2.747***	(1.045)
2022Q1	2.848***	(1.043)
2022Q2	2.892***	(1.042)
2022Q3	2.970***	(1.041)
2022Q4	3.036***	(1.041)
2023Q1	3.150***	(1.039)
2023Q2	3.280***	(1.038)
2023Q3	3.276***	(1.038)
2023Q4	3.285***	(1.038)
Pseudo R^2	0.3604	
LR Chi-squared	2979.84***	
N	25,310	

Note: ∗∗∗Significant at $p < 0.01$, ∗∗Significant at $p < 0.05$, ∗Significant at $p < 0.1$. Country as a categorical variable is included but not reported. [a] Reference category is international currency. [b] Reference category is speculative grade bond. [c] Reference category is 2017 Q1.

PSM, however, has two major drawbacks in the context of this study. It relies on estimating a propensity score through a regression model to restrict the data to a region of common empirical support. In cases with high-dimensional data or closely related variables such as currency, ratings or countries, collinearity issues that necessitate broader, less precise stratifications are faced. It also lacks the flexibility of defining acceptable thresholds or meaningful data bins for covariate balance, which might lead to a noncomparable control bond group, even with low imbalance and variance. For example, when comparing sovereign bonds, exact matching is required for variables such as country, as even small differences could introduce significant bias. In contrast, other variables, such as the coupon rate, could be allowed to vary within an acceptable range according to the financial literature, ensuring that comparability is maintained without over restricting the sample.

5.1.2. Coarsened Exact Matching

This study uses CEM, a comparatively less explored matching technique devised by Iacus, King, and Porro (2012). The CEM automates the manual method of matching formulated by Zerbib (2019), with the distinction that it is able to choose any n-number of units from the control group in defined proximity to the treatment unit analyzed. The CEM is a type of matching method known as monotonic imbalance bounding (MIB), which allows bounding of the higher level of imbalance in some characteristics of the distribution through an *ex-ante* choice (coarsening, in the case of CEM). In simpler terms, the level of imbalance is chosen *ex ante* by the user based on specific and substantive information about the data, and the MIB algorithm ensures that the imbalance is not larger than the data stratum defined. Any observation that does not match the stratum is therefore eliminated. Being regression model-free, it also allows the flexibility of using high-dimensional data and makes it suitable for use with proportionately very large control groups (Bertoni et al. 2020; S. M. Iacus, King, and Porro 2012).

A comparison between standardized mean differences of covariates of matched data through PSM and CEM is presented in Figure 8. While PSM can achieve a greater balance for some variables, such as the amount issued, especially maturity, it maintains slight variability in the categorical variables of currency, country and quarter, which results in noncomparability. The CEM, on the other hand, achieves exact matching in categorical variables. Stratification can be performed to reduce imbalance further in continuous variables.

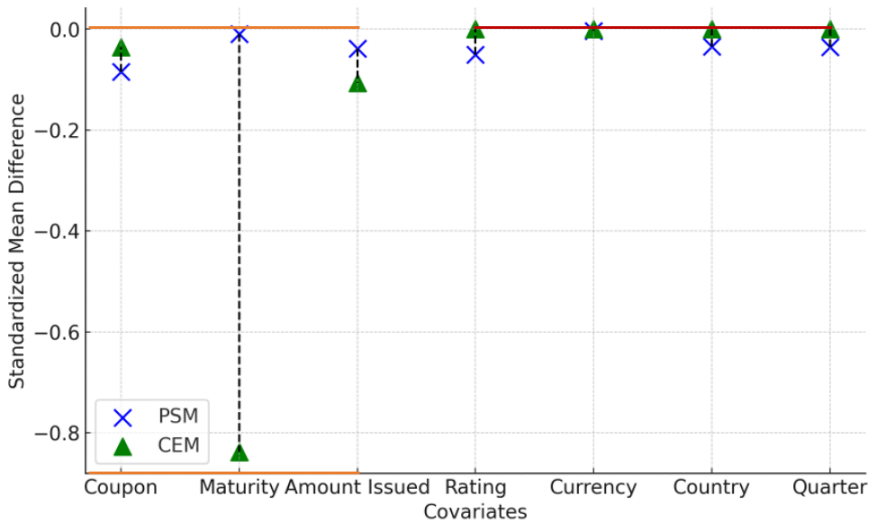


Figure 8: Comparison of standardized mean differences between matched control variables through Coarsened Exact Matching (CEM) and Propensity Score Matching (PSM). The imbalance acceptance threshold for the coupon, maturity and amount issued is specified as 0--1 (orange line), and that for the rest of the variables.

The steps outlined by Blackwell et al. (2009) are therefore followed to perform CEM on the curated dataset[14]. First, the imbalance factor is checked, given by the L1 global or multivariate imbalance distance between the treatment and control groups based on the variables to be matched. This can be interpreted through a similar reasoning strand used for R-squared estimates of any regression, i.e., the relative reduction in L1 distance matters more than absolute values. Larger values up to a maximum of 1 would indicate a larger imbalance between the groups, and perfect global balance would be indicated by $L1 = 0$.

Next, stratified bins are temporarily defined to set the imbalance limit. Since CEM provides the option of both automated and manual setting of strata within the same algorithm, matching is designed according to established financial literature:

For the EMDE country group as a treatment, exact matching is performed on the currency, quarter, and green labels. Credit ratings are classified into investment groups and speculative groups to increase the number of matched units. The maturity dates are divided into 5 groups from very short (less than 1 year) to very long (over 20 years) periods. The coupon rate is allowed to be automatically stratified, which results in +/- 0.5 coarsening. For a green labeled bond as a treatment, exact matching is performed on the currency, rating, quarter and country ticker[15] of a bond and is divided as above for the maturity date. The

[14] CEM is done using the Stata package cem designed by (Blackwell et al. 2010).

[15] Same country can have sovereign bonds being traded under separate tickers based on bond characteristics. For example, German DBR bonds have longer-term maturity and considered equivalent to 10-year US Treasury bonds. German OBL bonds have shorter-term maturities and higher yields. Both differ greatly in their market demand and supply.

coupon rate is allowed to be automatically stratified, which results in +/- 0.5 coarsening. For bonds with GSS use of proceeds as treatment, a similar procedure is followed as that of the green label.

No matched bond's issue date has a gap of more than 6 years. All bonds under consideration are "At Maturity" and "Senior Unsecured" (repaid as priority in case of default)[16]. After matching, the L1 distance is reduced to below 0.4 for all categories[17]. The matching results for the green bond treatment group are presented in Table 3. Note that the mean difference is zero to negligible for all covariates. For country group and use of proceeds stratifications, refer to the Appendix, Tables A3 and A4.

Table 3. Matching summary. Treatment: Green label.

Number of strata: 18927

Number of matched strata: 458

	0	1
All bonds	35799	998
Matched	1452	523
Unmatched	34347	475

Multivariate L1 distance: 0.38869765

Univariate distance:

	L1	mean	min	25%	50%	75%	max
Ticker	0.00	0.00	0	0	0	0	0
Currency	0.00	0.00	0	0	0	0	0
Quarter	0.00	0.00	0	0	0	0	0
Credit Rating	0.00	0.00	0	0	0	0	0
Coupon rate	0.21	0.05	0	0.17	0.125	-0.25	-0.5
Maturity	0.00	0.00	0	0	0	0	0

For each matched unit, CEM generates "importance" weights (weights assigned to normalize the variance of strata within the treatment and control groups), which can be used to estimate sample average treatment effects on the treated (SATT) via regular regression methods. All unmatched units are assigned a 0 (automatically eliminated if CEM weights are used). Each matched treatment and control member is assigned a value anywhere between >0 & ≤1 or ≥1 in accordance with equation 2:

$$\text{iWeight} = \frac{\frac{\text{Number of Treated Matched within strata}}{\text{Number of Controls matched within strata}}}{\frac{\text{Total controls matched}}{\text{Total treatments matched}}} \qquad (2)$$

[16] Should not be confused with 'unsecured' corporate bonds, which are not backed by collaterals. Sovereigns are mostly unsecured and issued under country's good faith.

[17] See Appendix, Table A3 and A4 for other matching results.

5.2. Empirical Model

The three hypotheses developed from the background and literature review (see Section 2) aim to test whether green labeling significantly mitigates risk for sovereign climate bonds, especially in the case of EMDEs, and whether it leads to a significant reduction in the cost of capital inequality between AEs and EMDEs. Based on these hypotheses, I employ a two-way fixed-effects model to examine both between- and within-group differences in the yield premium of green bonds compared with that of conventional sovereign bonds. Specifically, the CEM-weighted ordinary least squares (WLS) model is formulated according to equation 3:

$$Yield_{jit} = \beta_0 + \beta_1 Treatment_i + \beta_2 \text{ttm}_{jit} + \beta_3 \text{bidask}_{jit} + +\beta_4 \text{Amt}_{jit} + c_j + \mu_t + \epsilon_{jit} \quad (3)$$

The dependent variable is the quarterly ask yield-to-maturity ($Yield_{jit}$) of bond *j* of country *i* at quarter *t*. The ask yield is chosen because it represents the lowest price asked by the seller, providing the most conservative and realistic yield estimate, commonly used in the fixed-income literature (Baker et al. 2022; Fatica, Panzica, and Rancan 2021; Löffler, Petreski, and Stephan 2021; Zerbib 2019).

The variable of interest is $Treatment_i$, a binary variable representing the groups under consideration. For Hypothesis *H1*, $Treatment_i$ is 1 for the EMDEs and 0 for the AEs. If $\beta_1 > 0$ and is significant, it suggests that bonds in emerging markets are costlier due to higher yields over time. The regression is first run on the entire dataset and then stratified by green-labeled and conventional bonds.

Hypothesis H2 tests the existence of *greenium*. Here, the variable of interest is the binary green-bond classification ($Treatment_i$), where green-labeled bonds are assigned a value of 1 and the others are assigned a value of 0. If $\beta_1 < 0$ is significant, it indicates the presence of greenium due to lower yields over time. This regression is initially run across all countries and then run separately for EMDEs and AEs to account for regional differences.

Hypothesis H3 examines the risk-mitigating effect of the green label in line with GBP. The sample is restricted to conventional bonds only. The variable of interest is the binary project classification ($Treatment_i$) where bonds earmarked for green and sustainability projects but not labeled green are given a value of 1, and other bonds for corporate or nonreported purposes are assigned 0. If $\beta_1 = 0$, it suggests that GSS-purpose bonds not labeled green are not differentiated from conventional bonds by investors.

In fixed-income securities theory, substantial differences in liquidity can significantly affect yield levels and must be controlled (Dick-Nielsen, Gyntelberg, and Lund, n.d.; Jong and Driessen 2012; Zerbib 2019). This study controls for liquidity via three variables:

i. **Bid-ask spread ($\mathbf{bidask}_{jit}$):** The difference between the highest bid price and the lowest ask price, controlling for the liquidity premium in the secondary bond market. Typically, assets with narrow bid-ask spreads have high demand (Zerbib, 2019).
ii. **Tenor or term-to-maturity ($\mathbf{ttm}_{jit}$):** The time remaining before the bond matures, controlling for the maturity risk premium. It is inversely proportional to the bond yield, compensating for increasing risk over time (Buse, 1970).
iii. **Amount issued ($\mathbf{Amt}_{jit}$):** The amount issued by the bond, inversely proportional to yield and normalized via the natural logarithm of the variable.

All other bond characteristics are controlled through matching. Table 4 presents summary statistics for the dependent and time-varying control variables (refer to Table 1 for other variables). where c_j denotes the time-invariant country fixed effects, μ_t accounts for the country-invariant time fixed effects and ϵ_{jit} is the idiosyncratic error term.

Table 4. Summary statistics for time-varying variables

Variable	Observations	Mean	Std. Dev.	Min	Max
Ask Yield (%)	36,797	3.506	3.037	-6.735	22.506
Bid-Ask Spread	36,785	0.087	0.354	-0.444	20.968
TTM (quarters)	36,797	52.718	45.450	0	403

Note: TTM here stands for time-to-maturity.

To test for time-varying country-risk factors, I run the specification given equation 4:

$$Yield_{jit} = \beta_0 + \beta_1 Treatment_i + \beta_2 \text{ttm}_{jit} + \beta_3 \text{bidask}_{jit} + \beta_4 \text{Amt}_{jit} + \beta_5 \text{risk}_{jit} + c_j + \mu_t + \epsilon_{jit} \quad (4)$$

$risk_{jit}$ is a vector of economic determinants of bond *j* of country *i* at time *t* commonly used in the literature. It includes GDP growth, inflation, the fiscal deficit as a share of GDP, the current account balance as a percentage of GDP, and the real effective exchange rate (REER). The fixed-income securities literature shows that the effect of macroeconomic factors on bond yields can be explained by economic growth, price dynamics, fiscal health, debt sustainability, and terms of trade volatility indicators (Afonso and Nunes 2015; Poghosyan 2014; Zhou 2021). Damodaran (2012) suggest using market risk measures such as the yield of a sovereign bond itself (or its spread over U.S. Treasury Bonds) to control for the country risk premium. However, this study aims to measure the relative gap between sovereign bond

yields rather than the absolute risk associated with each country. Moreover, each period's global market risk is controlled by time fixed effects. A comprehensive description of the variables with their respective expected signs in the regression is given in the appendix (see Appendix Table A5).

Multicollinearity in the model decreases the precision of the coefficient estimates, making it difficult to determine which variables are statistically significant. Accordingly, I test for multicollinearity among the independent variables in the model by calculating the variance inflation factor (VIF), which identifies the correlation and the strength of that correlation between variables. The VIF of the independent variables is kept under 10[18] for all specifications.

6. Results

6.1. Main Results

The empirical results for all specifications in Tables 6-8 indicate that bond yields are significantly affected by regionality, labeling, and the underlying clean-energy investment. However, a limitation of using CEM is that it leads to the exclusion of several bonds where a suitable counterfactual was not found. This raises the concern that the results could be driven solely by data points selected through matching. To address this, I conducted a two-way ANOVA test on the unmatched sample to assess the significance of yield differences across groups. The results, presented in Table 5, show that the interaction term for green-labeled bonds and emerging

Table 5. Two-way ANOVA Test.

Number of observations =36797 R-squared=0.3265
Root MSE = 2.49302 Adj R-squared =0.3265

	Partial SS	df	MS	F	Prob>F
Model	110873.22	3	36957.74	5946.41	0.0000
GB	18.27	1	18.27	2.94	0.0864
EMDE	5467.71	1	5467.71	879.74	0.0000
GB#EMDE	1235.69	1	1235.69	198.82	0.0000
R-square	0.3265				
Adj R-squared	0.3265				
Root MSE	2.4930				
N	36797				

Note: Here, GB refers to Green Bonds, and EMDE refers to Emerging and Developing Economies.

Hypothesis *H1*: Regional differences in the cost of green bebt

[18] Multicollinearity is not a problem in estimating the model if VIF of the variables in the model are below 10 (Gujarati, 2021).

Table 6 displays the results for the regional difference in the cost of capital[19]. The results show that the cost of green capital is significantly greater for emerging economies than for the developed. Models (1)-(3) indicate that for investment-grade bonds, the ask yield is 57.4 basis points (bps) greater for EMDEs for all bonds, 58.9 bps greater for conventional bonds, and 57.2 bps greater for green bonds, all of which are significant at the 1% level. Green labeling reduces this difference by 1.7 bps. Models (4)-(6) demonstrate that for speculative-grade bonds, which include the majority of EMDE bonds issued, green labeling reduces the yield by 184.3 bps. The ask yield is higher by 481.5 bps for all EMDE bonds, 485.2 bps for conventional bonds, and 300.9 bps for green bonds, all of which are significant at the 1% level.

The liquidity control measures consistently have significant effects and strong explanatory power. Tighter bid-ask spreads, larger bond sizes, and longer maturities are associated with higher yields to compensate investors for the inherent risk of low liquidity. This effect is more pronounced for speculative-grade bonds, which is consistent with previous findings (Löffler, Petreski, and Stephan 2021; Zerbib 2019).

Table 6. Average Treatment Effect of the Treated (EMDE=1) estimated on the ask yield of bonds grouped according to green-labeling and credit rating.

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
EMDE [a]	0.574***	0.589***	0.572***	4.815***	4.852***	3.009***
	(0.0437)	(0.0440)	(0.195)	(0.0791)	(0.0808)	(0.167)
Term To Maturity	0.0136***	0.0135***	0.00891***	0.0292***	0.0297***	0.0196***
	(0.000350)	(0.000350)	(0.00195)	(0.00110)	(0.00113)	(0.00203)
Bid-Ask Spread	-2.256***	-2.224***	0.166	-2.761***	-2.712***	-4.094***
	(0.270)	(0.273)	(0.797)	(0.175)	(0.177)	(0.664)
Log (Amt Issued)	-0.0377**	-0.0321**	0.0510	-0.0125	-0.00180	0.134***
	(0.0158)	(0.0159)	(0.0783)	(0.0184)	(0.0189)	(0.0454)
Constant	2.756***	2.645***	-0.926	-2.072***	-2.364***	-3.273***
	(0.349)	(0.351)	(1.789)	(0.693)	(0.706)	(1.137)
Time FE	YES	YES	YES	YES	YES	YES
Observations	3,908	3,823	85	5,198	5,010	188
R-squared	0.663	0.664	0.960	0.612	0.612	0.905

Note: ∗∗∗Significant at $p < 0.01$, ∗∗Significant at $p < 0.05$, ∗Significant at $p < 0.1$. Standard deviation in parenthesis. Ask yield is truncated at 2.5% and 97.5% to reduce the influence of outliers. Here, EMDE refers to Emerging and Developing Economies. [a] Reference category is advanced economies (AE). Model 1 estimates the association between weighted ask yield and a country's development group for all investment-grade bonds in the sample. Model 2 restricts the sample to investment-grade conventional bonds, and Model 3 tests for only investment-grade green bonds. Models 4-6 follow the same order but for speculative-grade bonds.

Hypothesis *H2*: Estimating *greenium* across regions

Table 7 presents the results for Hypothesis *H2*, which estimates *greenium* across regions. Model (1) shows a small *greenium* of -5.14 bps for all countries combined, which is not significant at the 10% level.

[19] Macroeconomic risk factors are removed from this specification due to issues of multicollinearity. Inclusion of variables could reduce the magnitude of sovereign bond yield difference as it is itself explained by the macroeconomic factors. Lower GDP and real effective exchange rate, and higher fiscal deficit, inflation and current account deficit, translates into higher country risk for EMDEs. However, the relative difference between conventional and green bonds would remain significant.

Model (2) shows a small *positive* green bond premium of 5.81 bps for AEs, which is also not significant at the 10% level, and Model (3) shows a *greenium* of -17.3 bps for EMDEs, which is significant at the 1% level. However, these models do not control for country risk characteristics, which may introduce omitted variable bias. Models (4)-(6), which include country risk measures, yield significant results at the 1–5% level. Model (4) indicates a *positive* premium of 12.9 bps for green bonds for all countries, Model (5) shows a *positive* premium of 42.5 bps for AEs, and Model (6) reveals a *greenium* of -10.4 bps for EMDEs.

Coefficients of liquidity measures are more pronounced in emerging markets, particularly the bid-ask spread, indicating greater volatility. The explanatory power of macroeconomic factors is supported by the increasing R-squared trend from Model (1) to Model (6). Lower GDP growth rates (and higher inflation) are associated with lower yields, reflecting compensation for country risk, although the effects are not significant. A higher current account deficit significantly increases yields, especially for EMDEs, by 11 bps. Robustness checks using CEM k2k matched weights confirm the *greenium* results (see Appendix Table A7).

Table 7. Average Treatment Effect of the Treated (Green Bond=1) estimated on the ask yield of bonds grouped according to development-level.

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Green Bond [a]	-0.0514	0.0581	-0.178**	0.129***	0.425***	-0.104**
	(0.0494)	(0.0362)	(0.0833)	(0.0346)	(0.0413)	(0.0467)
Term To Maturity	0.0110***	0.00243***	0.0219***	0.0104***	0.00316***	0.0156***
	(0.000727)	(0.000587)	(0.00117)	(0.000482)	(0.000574)	(0.000674)
Bid-Ask Spread	-1.783***	0.208	-9.690***	-1.110***	-0.989***	-2.604***
	(0.245)	(0.147)	(0.629)	(0.256)	(0.237)	(0.492)
Log (Amt Issued)	0.832***	0.523***	0.868***	0.415***	0.559***	0.409***
	(.02873)	(.03166)	(.04138)	(0.0295)	(0.0365)	(0.0389)
GDP % growth	-	-	-	-0.582	-0.191	-0.152
	-	-	-	(0.370)	(0.503)	(0.534)
CAD (%GDP)	-	-	-	0.0603***	0.0371***	0.110***
	-	-	-	(0.00874)	(0.00950)	(0.0153)
CPI	-	-	-	0.00297	0.00353	0.0759***
	-	-	-	(0.00401)	(0.00368)	(0.0150)
Constant	0.950*	1.624***	1.483**	-9.123***	-11.85***	-6.172***
	(0.523)	(0.280)	(0.592)	(0.717)	(0.865)	(0.906)
Time FE	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES
Observations	1,975	1,038	936	1,401	747	653
R-squared	0.846	0.897	0.852	0.940	0.930	0.958

Note: ***Significant at $p < 0.01$, **Significant at $p < 0.05$, *Significant at $p < 0.1$. Standard deviation in parenthesis. Ask yield is truncated at 2.5% and 97.5% to reduce the influence of outliers. [a] Reference category is non-labeled conventional bond. Model 1 estimates the association between weighted ask yield and the green label for all countries in the sample without controlling for time-varying macroeconomic risk factors. Model 2 restricts the sample to AE economies, and Model 3 tests for EMDEs. Models 4--6 follow the same order but with risk factor controls.

Hypothesis *H3*: Differences in yields between non-labeled GSS bonds and conventional bonds

Table 8 presents the results for Hypothesis *H3*, which examines yield differences between non-labeled GSS bonds and conventional bonds. This specification excludes green-labeled bonds and considers only sovereign GSS bonds and their conventional counterparts. Model (1) shows a *positive* premium of 29.7 bps for GSS bonds across all countries, which is significant at the 1% level. Model (2) shows a small negative premium of -2.91 bps for AE GSS bonds, which is not significant at the 10% level. Model (3) shows a *positive* premium of 27.3 bps for EMDE GSS bonds, which is significant at the 1% level, indicating that GSS bonds that are not labeled green are costlier for emerging markets than conventional bonds are. This finding deviates from the corporate bond literature, which finds slightly lower pricing for GSS-rated bonds (Grishunin et al., 2023; Immel et al., 2021).

Table 8. Average Treatment Effect of the Treated (GSS=1) estimated on the ask yield of bonds.

VARIABLES	Model 1	Model 2	Model 3
GSS [a]	0.297***	-0.0291	0.273***
	(0.0587)	(0.0665)	(0.0672)
Term To Maturity	0.00781***	0.0172***	0.00758***
	(0.000818)	(0.00343)	(0.000858)
Bid-Ask Spread	2.076***	-0.107	2.055***
	(0.532)	(0.522)	(0.608)
Log (Amt Issued)	0.676***	-0.0754	0.672***
	(0.0364)	(0.0735)	(0.0387)
GDP % growth	-0.993	0.395	-1.606
	(0.823)	(0.633)	(1.073)
Constant	-12.33***	0.731	-11.91***
	(0.823)	(1.549)	(0.896)
Time FE	YES	YES	YES
Country FE	YES	YES	YES
Observations	538	98	439
R-squared	0.881	0.985	0.858

Note: ∗∗∗Significant at $p < 0.01$, ∗∗Significant at $p < 0.05$, ∗Significant at $p < 0.1$. Standard deviation in parenthesis. Ask yield is truncated at 2.5% and 97.5% to reduce the influence of outliers. Here, GSS stands for non-labeled Green, Social and Sustainability Bonds. [b] Reference category is non-labeled conventional bond. Model 1 estimates the association between weighted ask yield and the GSS mark for all countries in the sample. Model 2 restricts the sample to AE economies, and Model 3 tests for EMDEs.

6.2. Time Trends

The sample period from Q1 2017 to Q4 2023 can be divided into three phases: pre-COVID-19 (Q1 2017--Q4 2018), COVID-19 (Q2 2019--Q4 2021), and post-COVID-19 (Q1 2022--Q4 2023), coinciding with the Ukraine War era. Figure 9 illustrates the mean yields of sovereign green bonds and matched conventional bonds for AEs and EMDEs across these three phases. Over the period, the average yield for green bonds is slightly higher than that for conventional bonds in AEs, which is consistent with the results in Table 7. However, this gap decreases over time. For EMDEs, the average yield for conventional bonds is marginally greater than that for green bonds, with *greenium* peaking during the COVID-19 pandemic. The Kruskal–Wallis's equality-of-populations rank test, performed for green bonds and nongreen bonds

separately, rejects the null hypothesis that the three phases have similar yields (see Appendix: Table A6), indicating significant time trends.

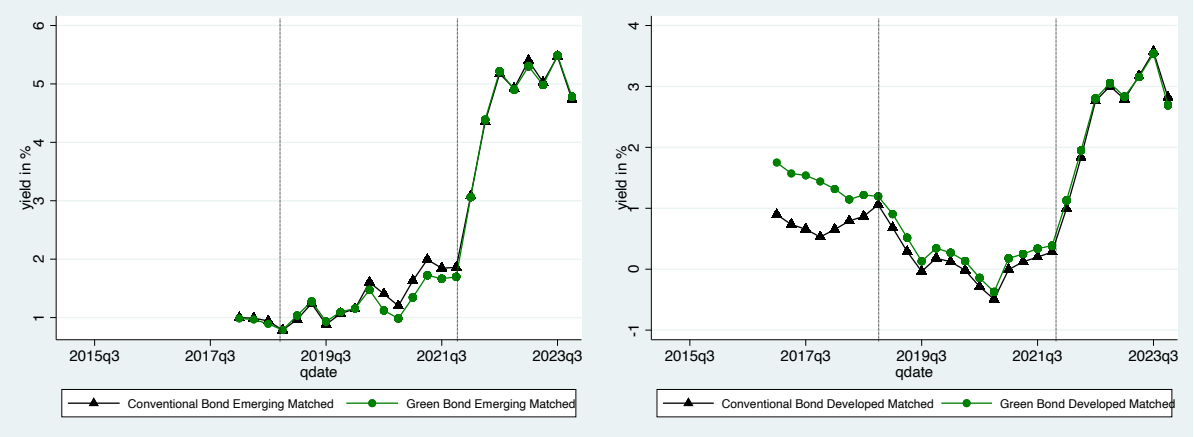


Figure 9: Quarterly mean yield of sovereign green (green circles) and matched sovereign conventional (black triangles) bonds for emerging (left graph) and developed (right graph) economies. The vertical dotted lines mark different phases of the sample period. There is no visual evidence of *greenium* (green line lies above black line) for developed economies. For emerging economies, after 2018 Q4 (left vertical line) and before 2022 Q1 (right vertical line), a clear *greenium* exists.

A two-way fixed effects model, using equation (5), is then applied to the matched dataset, with the periods as categorical variables instead of time fixed effects. The weighted regression results in Table 9 show a decreasing positive green bond premium for AEs over the three phases, although the decrease is not significant at the 10% level. For EMDEs, holding all else constant, the *greenium* is -27.2 bps greater (negative) in period 2 than in period 1, which is significant at the 10% level. The time differences for periods 1 and 3 are not significant. These results align with time trend studies of green bonds, demonstrating that green bonds are more resilient during volatile periods (e.g., COVID-19), with an average (negative) increase in *greenium* (Arat et al., 2023).

Table 9: Average Treatment Effect of the Treated (Green Bond=1) estimated on the ask yield of bonds over three time periods.

VARIABLES	Model (1)	Model (2)	Model (3)
Time to maturity	0.0135***	0.00302***	0.0224***
	(0.000691)	(0.000622)	(0.00105)
Bid-ask spread	2.967***	0.976***	6.997***
	(0.366)	(0.324)	(0.705)
Log (Amount Issued)	0.830***	0.541***	0.962***
	(0.0367)	(0.0400)	(0.0512)
Green Bond [a]	0.362**	0.456***	0.0819
	(0.147)	(0.115)	(0.242)
2019 Q2-2021 Q4 [b]	-1.285***	-1.094***	-1.476***
	(0.0906)	(0.0723)	(0.150)
2022 Q1-2023 Q4	0.796***	1.097***	0.282*
	(0.0885)	(0.0681)	(0.149)
1.GB# 2019 Q2-2021 Q4	-0.218	-0.0270	-0.354*

	(0.162)	(0.127)	(0.266)
1.GB# 2022 Q1-2023 Q4	-0.0147	-0.0638	0.0252
	(0.162)	(0.125)	(0.269)
GDP Growth (%)	-1.661***	-1.054***	-1.779***
	(0.352)	(0.377)	(0.475)
Inflation	0.0433***	0.0553***	0.0382***
	(0.00859)	(0.00785)	(0.0127)
REER	-0.0174***	-0.00266	-0.00910
	(0.00631)	(0.00840)	(0.00842)
Constant	-16.50***	-10.95***	-17.64***
	(1.057)	(1.186)	(1.311)
Country FE	YES	YES	YES
Observations	1,487	747	740
R-squared	0.890	0.915	0.895

Note: ***Significant at $p < 0.01$, **Significant at $p < 0.05$, *Significant at $p < 0.1$. Standard deviation in parenthesis. Ask yield is truncated at 2.5% and 97.5% to reduce the influence of outliers. [a] Reference category is non-labeled conventional bond. [b] Reference category is the 2017 Q1- 2019 Q1 period. Model 1 estimates the association between weighted ask yield and the green label for all countries in the sample. Model 2 restricts the sample to AE economies, and Model 3 tests for EMDEs.

6.3. Country risk and sovereign *greenium*

The results from Table 6 and Table 7 suggest an intriguing opposite relationship between the average green bond yield premia for AEs and EMDEs, implying a possible direct relationship between *greenium* and country risk. To test this, a scatter plot was generated, showing the average sovereign *greenium* for each country per quarter on the y-axis and the average sovereign yield as a proxy for the country's risk valuation on the x-axis. Figure 10 illustrates a positive correlation between these variables, indicating a direct relationship between a country's cost of debt and average *greenium*.

For empirical examination, a fixed-effects regression model was used with the average *greenium* of all matched bonds for each country per quarter as the dependent variable and the average sovereign conventional bond yield for each country per quarter as a proxy for the country's cost of debt (Damodaran, 2012). The results of the Fisher-type unit-root test show that the average *greenium* is stationary, and the Hausmann test predicts the suitability of the fixed effects regression model over random effects ($p<0.0005$) (see Appendix, Tables A8-A9). The Breusch–Pagan test indicates the presence of heteroscedasticity; therefore, robust errors are utilized, and the Wald test for joint significance indicates the use of time fixed effects (see Appendix, Tables A10-11). The model is presented in equation (5):

$$Greenium_{it} = \beta_0 + \beta_1 Yield_{it} + \beta_2 bidask_{it} + \beta_3 lnamt_{it} + \beta_4 ttm_{it} + \delta_t + \epsilon_{it} \quad (5)$$

where $Greenium_{it}$ is the average *greenium* for country *i* for quarter *t*, Yield_{it} is the average sovereign conventional yield for country *i* for quarter *t*, $bidask_{it}$ is the average bid-ask spread for country *i* for quarter *t*, $lnamt_{it}$ is the log of average amount issued for country *i* for quarter *t*, and ttm_{it} is the average

time-to-maturity for country i for quarter t. δ_t represents the time-fixed dummy ϵ_{it}, which are robust standard errors.

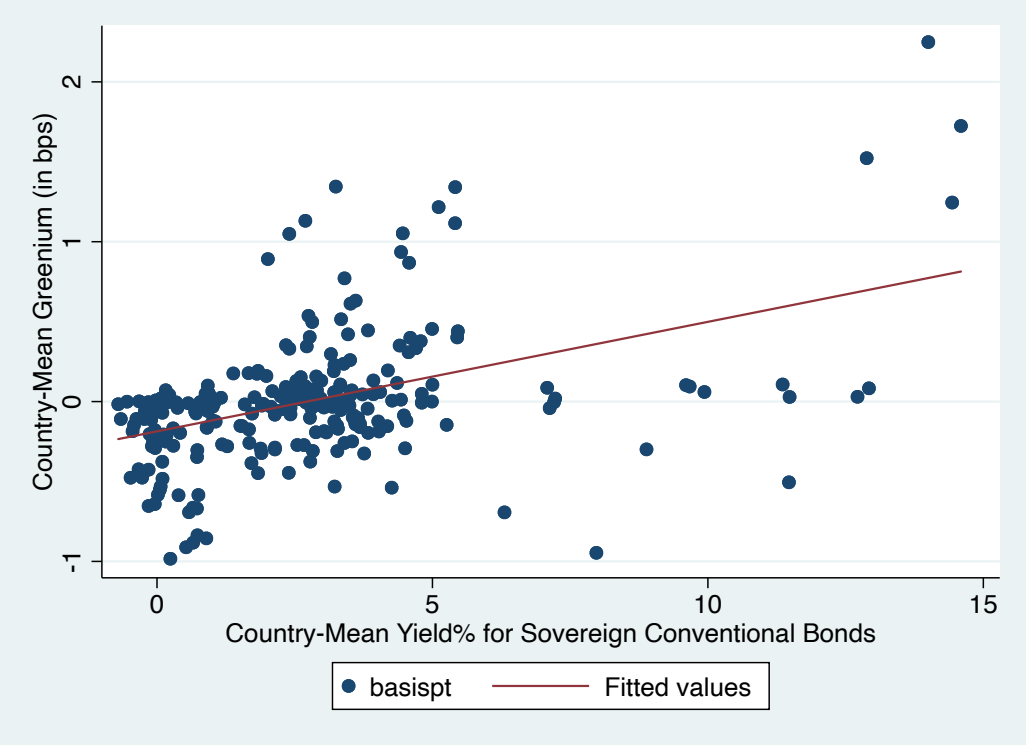


Figure 10: Direct relationship between average *greenium* yield and average conventional yield.

The results, shown in Table 10, confirm a positive and significant relationship between a country's cost of debt determined by macroeconomic risk factors and average *greenium.* Model (1) shows that for every one-unit increase in average sovereign conventional bond yield, the *greenium* increases by 5 bps, which is significant at the 1% level. Model (2) shows that for every 1 bps increase in average sovereign conventional bond yield, the *greenium* increases by 14.7 bps, which is significant at the 5% level. These results are consistent with those of (Tomczak, 2024), who used a similar model for sovereign green bonds but without a matching technique or triple control for liquidity.

Table 10. Association between country-risk and *greenium.*

VARIABLES	Model (1)	Model (2)
Conventional Bond Yield	0.0587***	0.147**
	(0.0195)	(0.0662)
Bid-Ask Spread	-0.584	0.148
	(0.439)	(0.263)
Log (Amount Issued)	-0.0595**	-0.577**
	(0.0265)	(0.258)
Time to maturity	-0.00329***	-0.00652**
	(0.000955)	(0.00274)

Constant	1.586***	13.90**
	(0.589)	(5.986)
Time FE	YES	YES
Observations	260	260
R-squared	0.391	0.358
Number of panel ID		23

Note: ***Significant at $p < 0.01$, **Significant at $p < 0.05$, *Significant at $p < 0.1$. Standard deviation in parenthesis. Ask yield is truncated at 2.5% and 97.5% to reduce the influence of outliers. Here, dependent variable is the country-mean *greenium* for each quarter. Conventional bond yield is averaged across each country.

7. Discussion and Policy Implications

This research provides the first comprehensive global, bond-level study of the causal effects of sovereign green bond issuance on a country's cost of debt associated with green finance. Specifically, it estimates the regional variation in sovereign *greenium* between developmentally segregated economies to assess the viability of sovereign green bonds as risk-mitigating public instruments for climate finance, especially in the case of emerging economies. This study is particularly timely, given the urgent need for direct government participation in green finance (IMF) and the exponential share of sovereign-issued bonds in the green bond market. The findings demonstrate that the green labeling of sovereign GSS bonds has distinct advantages for emerging economies, which is in line with the results of (Xiao, n.d.).

7.1. Implications for emerging and developing economies

The issuance of sovereign green bonds as benchmark climate securities presents distinct risk-mitigating advantages for emerging economies as a public green finance instrument. Sovereign green bonds can reduce the cost of climate debt in three ways:

First, sovereign green bonds in emerging economies are found to trade at yields approximately 10.4 bps lower than those of their conventional counterparts. This suggests a robust demand, indicative of investor confidence and the potential for future growth despite administrative and transaction costs associated with green labeling. Back-of-the-envelope calculations using IMF[20] cost estimates reveal net benefits for emerging economies even for minimal *greenium*. For a representative USD 750 million, 10-year, 6.125% coupon bond at a yield of 6.17%, the study finds an additional green labeling cost of 266 thousand USD. However, an average 4 bps lower yield after green labeling leads to 1.9 million USD more funds raised by the bond.

[20] Retrieved from IMF, "Sovereign ESG Bond Issuance, A Guidance Note for Sovereign Debt Managers". https://www.imf.org/en/Publications/WP/Issues/2023/03/11/Sovereign-ESG-Bond-Issuance-A-Guidance-Note-for-Sovereign-Debt-Managers-530638. Last access: 2 August 2024.

Second, the premium of 27.3 bps for unlabeled sustainable bonds over conventional bonds suggests a market preference for transparency provided by green labels. This, coupled with the significant spillover effects of sovereign green reporting on corporate bond information asymmetry reported by Xiao (n.d.) and Oman (n.d.), underscores the need for nationally standardized verification processes.

Third, the study highlights a substantial reduction in yield disparities for speculative-grade bonds. Owing to underdeveloped financial markets, emerging economies generally command low credit ratings (R. Cheng et al., 2023), leading to high country risk premiums. This disadvantage over developed economies is offset by an average of 185 bps for sovereign, green-labeled bonds. Moreover, evidence suggests that demand for emerging economy sovereign green bonds increases during volatile times (e.g., the COVID-19 pandemic). The result is corroborated by similar studies on private bonds that find lower green yields during volatile markets (Arat et al., 2023). Both cross-sectional and time series resilience underscores the strong position of sovereign green bonds during periods of market uncertainty.

To solidify the risk-mitigating nature of green-labeled sovereign bonds, this study finds that higher average yields on conventional bonds correspond with greater yield differentials between conventional and green bonds. Specifically, for every 1 basis point increase in conventional bond yields, the yield gap between conventional and green bonds widens by 14.7 basis points. This finding indicates that in riskier countries and during volatile periods, sovereign green bonds attract relatively higher demand. These findings align with those of Tomczak (2024).

However, several concerns regarding sovereign green bonds have emerged. Liquidity analyses reveal that their demand is, on average, volatile, leading to potential price instability. Yields also exhibit greater sensitivity to issuance size and maturity. Furthermore, the lack of financial institutions in developing countries presents a more systematic challenge than do administrative costs or transparency issues (Ameli et al., 2021). Macroeconomic risks, such as high current account deficits and inflation, can exert a relatively strong influence on green bonds. Despite these challenges, the study emphasizes the role of sovereign green bond issuance as *benchmark green securities*, providing a clear signal of a national long-term climate strategy and hence suggesting potential mitigation of country risk associated with climate debt.

7.2. Implications for developed economies

In contrast with other findings on general *greenium* (Ivashkovskaya & Mikhaylova, 2020), this study shows that sovereign green bonds in developed economies, surprisingly, trade at a yield 42.5 bps higher

than that of their conventional counterparts. This suggests a higher cost of debt for green-labeled instruments, which could be attributed to the “safe haven effect”.

Advanced economy green bonds sell in competition with their own conventional sovereign bonds, which are widely regarded as risk-free investments. Both sell at low liquidity and low demand volatility. Moreover, no significant price difference is observed between conventional and non-labeled sustainable bonds, indicating that a yield premium is solely explained by the green label. In fact, recent trends reported by Bloomberg News indicate a shift in investor preference toward GSS bonds over green-labeled bonds in the United States. Further analysis is needed to understand these pricing dynamics for developed countries’ sovereign green bonds.

8. Conclusion

This study estimates the relative cost of green debt for developed and emerging economies using sovereign green bonds as an instrument. This study has significant policy implications for the green labeling of sovereign bonds. By employing a coarsened exact matching technique to create a control group of conventional bonds that are closest possible counterfactuals to each green bond, it provides a comparative analysis of the magnitude and volatility of *greenium* across developed and emerging economies. Notably, this research is the first to estimate yield differences associated with sustainable, non-labeled bonds and to explore the direct relationship between country risk and sovereign *greenium*. The findings clearly demonstrate the risk-mitigating effects of green certification for emerging markets—a benefit that does not extend to advanced economies.

However, the study has certain limitations. It does not delve into other determinants of sovereign *greenium*, such as ratings or currency, as these factors are controlled through matching. Additionally, it does not explore the impact of sovereign green issuance on other sources of public or private finance, corporate bonds, or the effect of bond proceeds on environmental goals. Assessing the exact cost of institutional development for green certification falls beyond the scope of this paper, making it challenging to determine whether green labeling would be net profitable for each country. However, within a broader context, it is expected to support countries in their path toward a green transition.

As Stern and Stiglitz (2023) argue, even if green instruments are exposed to market fluctuations, *“green transition is coming at a time when, both because of persistent deficiencies of aggregate demand and advances in technology...the macroeconomic opportunity costs of strong climate actions may be especially low and the benefits particularly high.”* These conditions suggest that, despite volatility, sovereign *greenium* is likely to remain significant for emerging economies. The sustainable bond market

represents just one step in addressing the substantial challenge of green finance. Further research is essential to explore public and private green bond issuance and other aspects of public climate finance that can sustainably support the green transition.

Data Statement

The data that support the findings of this study are available from Bloomberg Inc., but restrictions under agreement with Bloomberg apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data for country risk measures are available from the IMF IFS[21] and REER dataset provided by Breugel, 2023[22].

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Appendix

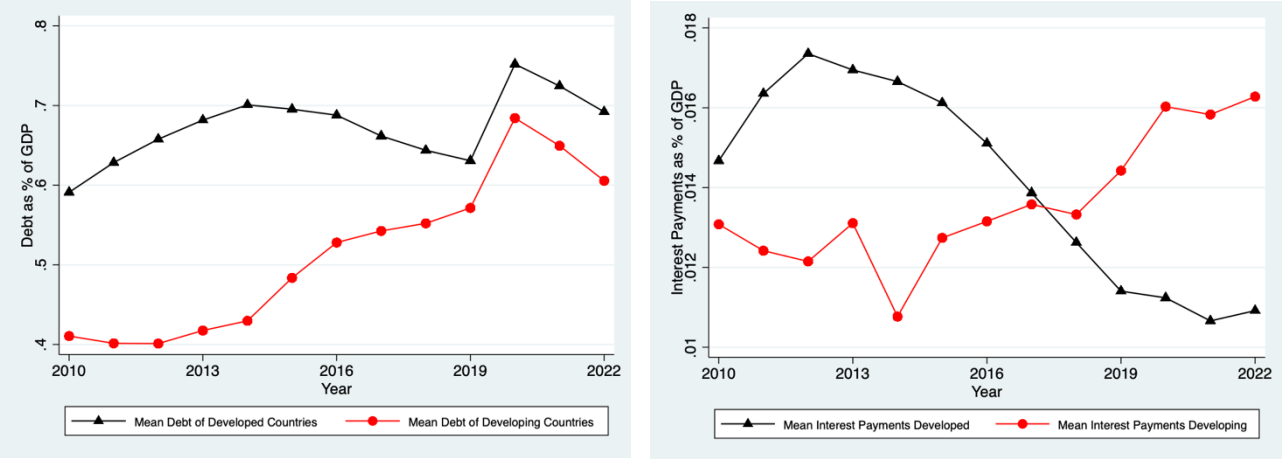


Figure A1: Regional difference in cost of debt. The graph shows yearly mean debt as % of GDP of developed countries (black triangles) and developing countries (red circles) in the left graph and yearly mean interest payments as % GDP in the right graph. While debt as proportion of GDP is increasing for both categories, interest payments are disproportionately rising for developing countries due to higher cost of debt. Sourced from World Economic Outlook, 2023, International Monetary Fund and authors' calculations.

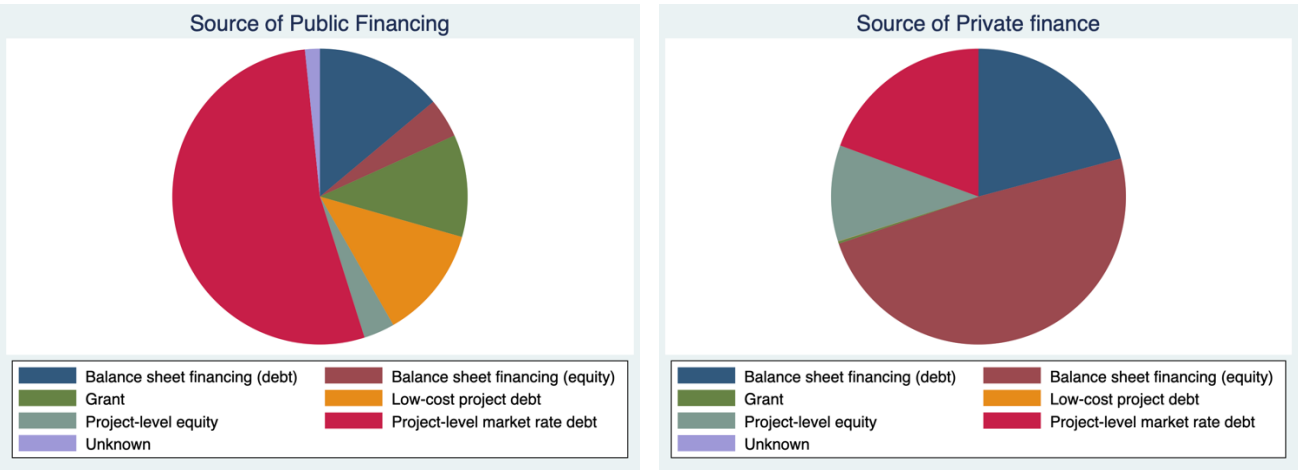


Figure A2: Global private and public investments as of 2022. Only Grants and Low-cost project debts are not exposed to market-risk. Proportions are uniform across developed and developing regions, except for a much higher share of public over private debt in developing regions. Sourced from Global Landscape of Climate Finance 2022, Climate Policy Initiative (CPI) and authors' calculations.

Table A1: Chile's green-labeled vs non-, green-labeled sovereign bond pairs:

Quarter	Yield	Bond ID	Amount Issued	Coupon	Maturity	Rating	Green Bond
2021q2	3.223	BO8615516	1.50E+09	3.5	2053q2	A-	0
2021q3	3.455	BO8615516	1.50E+09	3.5	2053q2	A-	0
2021q4	3.288	BO8615516	1.50E+09	3.5	2053q2	A-	0
2022q1	4.054	BO8615516	1.50E+09	3.5	2053q2	A-	0
2022q2	5.014	BO8615516	1.50E+09	3.5	2053q2	A-	0
2022q3	5.858	BO8615516	1.50E+09	3.5	2053q2	A-	0
2022q4	5.395	BO8615516	1.50E+09	3.5	2053q2	A-	0
2023q1	5.11	BO8615516	1.50E+09	3.5	2053q2	A-	0
2023q2	5.143	BO8615516	1.50E+09	3.5	2053q2	A-	0
2023q3	5.909	BO8615516	1.50E+09	3.5	2053q2	A-	0
2023q4	5.067	BO8615516	1.50E+09	3.5	2053q2	A-	0

Quarter	Yield	Bond ID	Amount Issued	Coupon	Maturity	Rating	Green Bond
2021q2	3.204	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2021q3	3.461	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2021q4	3.243	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2022q1	3.967	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2022q2	4.982	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2022q3	5.813	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2022q4	5.391	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2023q1	5.186	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2023q2	5.199	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2023q3	5.993	AZ1913575	2.32E+09	3.5	2050q1	A-	1
2023q4	5.124	AZ1913575	2.32E+09	3.5	2050q1	A-	1

Table A2: Detailed distribution of Use of Proceeds

Conventional Bonds	Frequency	Green, Social and Sustainability Bonds	Frequency
#N/A Field Not Applicable	1,343	Capital Expenditures Sustainability	1
Acquisition Financing	1	General Corporate Purposes Green Bond/Loan	2
Bond Exchange General Corporate	2	General Corporate Purposes Refinance Green	4
Capital Expenditures	1	General Corporate Purposes Refinance	1
Collateral for Swap	1	General Corporate Purposes Sustainability	1
General Corporate Purposes	247	General Corporate Purposes Sustainability	2
General Corporate Purposes Investment	4	Green Bond/Loan	99
General Corporate Purposes Investment	1	Pandemic Sustainability Bond/Loan	2
General Corporate Purposes Pandemic	4	Project Finance Green Bond/Loan	2
General Corporate Purposes Project	2	Project Finance Refinance Sustainability	1
General Corporate Purposes Refinance	75	Refinance Green Bond/Loan	5
General Corporate Purposes Refinance	1	Refinance Pandemic Sustainability	2
Investment	7	Sustainability Bond/Loan	44
Pandemic	8	Sustainability Linked	2
Project Finance	1		

Project Finance Refinance	2		
Refinance	54		
Refinance Pandemic	4		
Social Bond/Loan	13		
Total	1,771	Total	168

Table A3: Matching Summary, Treatment- EMDE

Multivariate L1 Distance: 0.98263944

Univariate Distance:

	L1	mean	min	25%	50%	75%	max
Currency	0.83773	7.2736	2	4	8	16	1
Rating	0.7478	-3.4692	0	-4	-3	-1	0
Coupon	0.4802	2.9951	0	2.475	3.275	3.275	6.885
Maturity (stratified)	0.06186	5.90E-05	0	0	0	0	0

Number of strata: 9282

Number of matched strata: 914

	0	1
All	16199	20598
Matched	8710	4982

Multivariate L1 distance: .53235902

Univariate Imbalance

	L1	mean	min	25%	50%	75%	max
Currency	2.90E-15	-2.70E-13	0	0	0	0	0
Rating (stratified)	1.30E-15	-1.30E-12	0	0	0	0	0
Coupon	1.70E-15	-5.90E-17	0	0	0	0	0
Maturity (stratified)	0.34553	0.09575	0	-0.05	-0.125	0.25	0.5
Green Bond	5.10E-15	2.00E-14	0	0	0	0	0

Table A4: Matching Summary, Treatment- GSS:

Multivariate L1 Distance: 0.99692038

Univariate Distance:

	L1	mean	min	25%	50%	75%	max
Currency	0.43059	4.5966	2	0	14	5	1
Rating	0.54132	-2.8146	0	-4	-6	-3	0
Coupon	0.41414	-0.88338	0	-0.55	-1.25	-1.8	-2.29
Maturity (stratified)	0.4552	11.937	3	16	14	16	-198

Number of strata: 18636

Number of matched strata: 168

	0	1
All	35396	403
Matched	410	206

Multivariate L1 distance: 0.44838188

Univariate Imbalance

	L1	mean	min	25%	50%	75%	max
Ticker	2.90E-16	-3.60E-15	0	0	0	0	0
Currency	5.80E-16	-3.90E-14	0	0	0	0	0
Quarter	6.80E-17	1.40E-13	0	0	0	0	0
Rating	1.00E-16	2.30E-14	0	0	0	0	0
Coupon	0.17783	-0.1246	0	0.16	-0.5	0.14	-0.375
Maturity (stratified)	3.50E-16	-3.60E-15	0	0	0	0	0

Table A5: Summary of variables used in the regression

Variables	**Exp. Sign**	**Description**	**Source**
Dependent Variable			
Ask-Yield	NA	Quarterly rate of return on the respective bond	Bloomberg
Bond Characteristics			
Coupon Rate (in %)	+	Interest rate paid by the bond at the time of	Bloomberg
Issue Date	NA	Date at which the bond was issued by the	Bloomberg
Tenor (in quarter)	+	Length of time remaining until the bond	Authors'
Bid-Ask Spread	+	A proxy of a liquidity measure. A lower spread	Authors'
Bond Rating	-	Standard letter-based credit scores given to the	Bloomberg
Country of Issue	Fixed	Country which issued the bond.	Bloomberg
Currency of Issue	(Categorical)	Currency in which the bond was issued.	Bloomberg
Amount Issued (in	+	Total amount raised by the issue of bond.	Bloomberg
Use of Proceeds	-	The purpose/project for which the amount	Bloomberg
Green Labeled	1/0 "-"	A dummy variable equals 1 if the bond is	Bloomberg
EMDE Category	1/0 "+"	A dummy variable equals 1 if country of issue	IMF
Country Risk Measures			
GDP Growth (in %)	-	Quarterly GDP growth of the country of	IFS IMF
Consumer Price	+	Quarterly CPI. The higher the inflation, the	IFS IMF

REER	+/-	Quarterly real effective exchange rate (REER).	Bruegel,
Fiscal Deficit	+	Quarterly measure, can lead to higher yield due	IFS IMF
Current Account	-	Quarterly measure, can lead to lower yield if	IFS IMF

Table A6: Kruskal–Wallis's equality-of-populations rank test for time trends

Green Bond=0:

Period	Observations	Rank Sum
1	11,196	2.02E+08
2	14,852	2.13E+08
3	9,751	2.27E+08

Chi-squared= 4393.053 with 2 d.f.

Probability=0.0001

Chi-Squared with ties= 4393.053 with 2 d.f.

Probability=0.0001

Green Bond=1:

Period	Observations	Rank Sum
1	82	38845.5
2	357	91467
3	559	368188.5

Chi-squared= 425.416 with 2 d.f.

Probability=0.0001

Chi-Squared with ties= 425.416 with 2 d.f.

Probability=0.0001

Table A7: Ask yield (with CEM k2k weights)

VARIABLES	Model 1	Model 2	Model 3
Green Bond=1	0.149***	0.475***	-0.0967*
	(0.0433)	(0.0519)	(0.0580)
Term To Maturity	0.0103***	0.00299***	0.0152***
	(0.000675)	(0.000818)	(0.000915)
Bid-Ask Spread	1.015***	0.843***	2.442***
	(0.322)	(0.296)	(0.606)
ln(Amt Issued)	0.422***	0.593***	0.415***
	(0.0395)	(0.0494)	(0.0517)
GDP growth %	-0.513	-0.111	-0.0228
	(0.521)	(0.701)	(0.752)

Inflation	0.0476***	0.0239*	0.0983***
	(0.0123)	(0.0132)	(0.0216)
CAD	0.00438	0.00331	0.0832***
	(0.00565)	(0.00513)	(0.0210)
Constant	-9.154***	-12.52***	-6.214***
	(0.964)	(1.182)	(1.217)
Country FE	YES	YES	YES
Time FE	YES	YES	YES
Observations	736	390	346
R-squared	0.939	0.930	0.958

Note: Model 1 estimates the association between k2k-weighted YTM and GB for all countries in the sample. Model 2 restricts the sample to AE economies, and Model 3 tests for EMDEs. The yield is truncated at 2.5% and 97.5% to reduce the influence of outliers. The standard deviations in parentheses. ***, **, and * represent coefficients significantly different from 0 at the 1%, 5%, and 10% significance levels, respectively.

Table A8: Unit Root Test

```
Fisher-type unit-root test for basispt
Based on augmented Dickey-Fuller tests
---------------------------------------
Ho: All panels contain unit roots         Number of panels       =     23
Ha: At least one panel is stationary      Avg. number of periods =  11.30

AR parameter: Panel-specific              Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Not included
Drift term:   Not included                ADF regressions: 3 lags
------------------------------------------------------------------------------
                                Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(36)   P       207.3658       0.0000
 Inverse normal            Z        -6.7447       0.0000
 Inverse logit t(59)       L*      -15.3542       0.0000
 Modified inv. chi-squared Pm       20.1956       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```

Table A9: Hausman Test

	Coefficients (b) fixed	(B) random	(b−B) Difference	sqrt(diag(V_b−V_B)) S.E.
yield_con	.147466	.0571034	.0903626	.0383026
bid_ask	.1475504	−.0278465	.1753969	.0758703
lnamt	−.5769547	−.0508978	−.5260569	.1871781
mtyq	−.0065177	−.0051103	−.0014073	.0010713
qdate				
229	.0433322	.0280823	.01525	.0060563
230	.0089821	−.0134915	.0224737	.009015
231	−.0026177	−.0349038	.0322861	.0142075
232	.3016162	.3186575	−.0170412	.0190607
233	.3345895	.3532813	−.0186918	.0225544
234	.3432098	.3625219	−.0193121	.0217935
235	.3693082	.4177151	−.0484069	.0255726
236	.3230714	.3358184	−.0127471	.0356565
237	.3942464	.3700167	.0242297	.044981
238	.4759821	.4252407	.0507414	.0555738
239	.4636657	.4317431	.0319226	.0491613
240	.4978529	.4668534	.0309996	.0489056
241	.4254868	.4304163	−.0049295	.0559793
242	.5128653	.5005464	.0123189	.0609035
243	.4923985	.4759648	.0164337	.0677824
244	.4880199	.5084194	−.0203995	.0615752
245	.459497	.4780045	−.0185075	.0641162
246	.4266341	.4486422	−.0220081	.064314
247	.4519851	.4765347	−.0245496	.0681237
248	.2640251	.3815666	−.1175415	.0569325
249	.0894412	.3017109	−.2122697	.0575034
250	.041248	.3517504	−.3105024	.0791722
251	.0025991	.3234594	−.3208603	.0816945
252	.0379624	.3404592	−.3024967	.0745863
253	.0272745	.3237853	−.2965108	.0774528
254	−.0954489	.2377965	−.3332453	.0883241
255	.0323921	.2936993	−.2613072	.0679684

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi2(**20**) = (b−B)'[(V_b−V_B)^(−1)](b−B)
= **110.16**
Prob>chi2 = **0.0000**
(V_b−V_B is not positive definite)