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VANISHING ANOMALY OR PERSISTING FORCE?
**EXPLORING THE TEMPORAL VARIABILITY OF THE GREEN BOND
PREMIUM**

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Abstract: This study investigates the temporal variability of the green bond premium. Employing a rigorous matching method and a fixed-effects panel regression model, no yield differential between green and comparable conventional bonds of economic and statistical significance could be evidenced. Whilst this finding is in line with traditional pricing theory, it challenges prior greenium literature. Further exploration suggests a role of the green halo effect on pricing dynamics, thereby broadening the greenium discourse to the possibility of issuer-wide positive externalities resulting from green bond issuance as opposed to a theoretical greenium capturing the entire pricing benefit of green bond issuance.

Keywords: Green Bonds, Green Bond Premium, Sustainable Finance, Impact Investing, Fixed Income

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1. INTRODUCTION

Scientific evidence unequivocally points to greenhouse gas emissions from human activities as a major driver of global warming, leading to rising temperatures, extreme weather events, accelerated biodiversity loss and environmental damages. In recognition of the need to combat climate change, the international community has committed to swift actions to limit global warming to well below two degrees Celsius (UNFCCC, 2015).

Such ambitious emissions reduction targets necessitate major increases in green investments, both public and private, for the ecological transformation of societies and economies globally. To attract capital towards these green investments, a number of green financial innovations such as green bonds have emerged (OECD, 2015).

Green bonds are debt securities issued by public and private entities with proceeds designated for the financing of green projects (Berrou et al., 2019). Although making up only 2.42% of the total bond market in 2018 (Fatica et al., 2021), the cumulative green bond issuance volume has reached USD 2.16 tn in 2022 since the inception of the green bond market segment in 2007. Expected issuances of USD 1 tn in 2023 alone underline the exponential growth of the market segment (S&P, 2022).

Whether green bonds command a green bond premium (“*greenium*”), a yield differential to their comparable vanilla correspondents, remains a contentious issue amongst researchers as current findings remain largely inconclusive.

Within the body of studies in favour of a green premium, one strand has emerged reinterpreting parts of it as a misconceived liquidity premium, attributing the yield spread between green and equivalent non-green securities partly or entirely to a mismatch of insufficient supply for green investments against enormous demand for these securities (cf. Febi et al., 2019; Doronzo et al., 2021; Molino et al., 2023). Given the rapid growth of the green bond market offering, such a liquidity premium would likely vanish over time. In an attempt to

segregate a possible liquidity premium from a green premium, this thesis aims to answer:

R1: *Does greenium display temporal variability?*

To study this overarching research question, pursuant auxiliary questions are to be investigated:

R2: *Do green bonds command lower yields than comparable conventional bonds?*

R3: *If confirmed, what is the liquidity-adjusted magnitude of this greenium?*

This thesis critically evaluates prevailing methodological and explanatory greenium approaches. Building on that review, it contributes to the growing body of currently inconclusive greenium literature using an optimised methodological approach on the latest green bond market data. Findings have practical implications for issuers, investors, asset managers, policymakers and researchers alike.

The remainder of this paper is structured as follows. In section 2, the background for the analysis will be provided. A literature review will synthesise the current state of greenium research in section 3. In section 4, the methodology of the analysis will be laid out. Section 5 presents and discusses the findings of the empirical analysis. Ultimately, section 6 presents this paper's final conclusion on the basis of the prior analysis and proposes future research.

2. BACKGROUND

2.1 Sustainable and Green Finance Frameworks and Terminology

Characterised by different assumptions, models and resultant estimates, a plethora of bodies have assessed capital investment needs required to decarbonise economies in line with the 2015 Paris Agreement objectives. Although public and private sector sustainable financing has increased significantly over the past years, there is a broad consensus that current investment flows are still grossly insufficient to finance the transition to net zero¹ (Tiftik and Mahmood, 2023). The structured attempt to bridge this investment gap and to integrate environmental

¹ An often-referenced concept in the context of environmental sustainability is carbon neutrality which describes a state in which the emitting of carbon is outbalanced by the removal of said emissions from the atmosphere. Net Zero extends this concept not just to carbon but all greenhouse gas emissions (World Economic Forum, 2022).

concerns into business, financing and investment decisions to channel funds into projects with environmental benefits is commonly referred to as Green Finance (Berrou et al., 2019).

Much like the varying estimates of sustainable investment needs, there is also significant heterogeneity in the application of sustainable finance jargon. Albeit frequently employed interchangeably and characterised by a lack of precise boundaries, this paper follows the UNEP (2016) definitions of sustainable finance terminology: In a broad definitory approach, **Sustainable Finance** aims at integrating environmental, social, economic and governance criteria, as defined by the UN Sustainable Development Goals, into financing and investment decisions. Representing environmental issues within sustainable finance, **Green Finance** aims at the furtherance of environmental protections and the reduction of greenhouse gas emissions through the provision of investment, financing and financial services for projects and initiatives with environmental benefits. It thereby encompasses climate adaption and mitigation (“**Climate Finance**”) as well as other environmental dimensions, collectively denoted as Green Finance.

2.2 Definition of Green Bonds

Green Bonds are amongst the financial innovations emerging out of this structured approach to integrate green consideration into finance decisions. In line with most green bond definitions, Hyun et al. (2020) define green bonds as debt securities that exclusively fund projects with environmental benefits. In relation to conventional bonds, green bonds hold the same characteristics and properties as their vanilla correspondents other than that their proceeds are earmarked for environmentally beneficial projects.

Beyond the above definition, the absence of scholarly consensus and authoritative regulation governing what constitutes a green bond exposes this novel asset subclass to *greenwashing*² as emitters face no regulatory requirements for labelling their bonds as green.

² Barclays (2015) defines greenwashing in the context of green bonds as “green bond issues that fund projects that lack sufficient environmental benefits”. It refers to the deliberate misrepresentation of information as to the environmental benefits of a project to reap the reputational and financial benefits associated with a green image.

To hedge the reputational risk arising from such greenwashing suspicions, some issuers opt to certify green issuances against green bond standards. Currently, the Climate Bonds Standard (CBS) by the Climate Bonds Initiative (CBI) and the Green Bond Principles (GBP) by the International Capital Markets Association (ICMA) are the most authoritative certification schemes in the green bond market. Conversely, many issuers refrain from even labelling their issuances as green despite using proceeds to finance eligible projects. The rationale for not labelling green bonds as such could be to avoid additional disclosure, verification costs or a lack of awareness of market interest in green-labelled bonds (cf. OECD, 2015; VanEck, 2020).

2.3 Green Bond Verification Schemes

Amid a regulatory vacuum, the enactment of standardised frameworks by independent third-party actors, such as the **Green Bond Principles**, endeavour to confer legitimacy and transparency to green bonds and avert greenwashing. They are guidelines regarding four chief components, namely (1) use of proceeds, (2) process for project evaluation and selection, (3) management of proceeds and (4) reporting. Adherence and certification against them is voluntary but ICMA (2018) recommends the appointment of external reviewers to attest GBP compliance in the form of a second-party opinion, certification or scoring/rating.

The related **Climate Bonds Standard** resembles the GBPs in that it mandates post-issuance reporting and the investment of proceeds in alignment with a predefined framework. Yet, the CBS aims to eliminate the inherent subjectivity of the GBPs which are fully integrated into the CBS by mandating much stricter and more detailed provisions. CBI (2023a) vows that these specifications are rooted in science-based criteria and benchmarked against the Paris Agreement 1.5 degree target. Yet, CBI (2016) also disclaims that CBS remains an environmental, not a financial standard and that “investors must do their own credit analysis.”

As the most comprehensive green bond standard yet, the soon-to-be-enacted **European Green Bond Standard** (EUGBS) is expected to become the new benchmark standard for green

bond issuances. As part of their legislative effort around the European Green Deal, the European Commission (2023) aims to harmonise national green finance legislation to “better direct financial and capital flows to green investments”. All proceeds are to be invested in alignment with the EU Taxonomy³. Pre- and post-issuance reporting is mandated and must contextualise how green investments made under the EUGBS label feed into an issuer’s broader green transition plans. Certification against the EUGBS remains voluntary, but current proposals stipulate mandatory private reviews by publicly registered and approved reviewers in order to be certified. The enactment by law and public supervision confers democratic legitimacy to the EUGBS next to the privately-maintained CBS and GBP (European Commission, 2023).

2.4 Green Bond Market Development

Superficially, green bond issuance seems burdensome for emitters due to their additional reporting requirements, expenses associated with third-party certification and the restriction to allocate proceeds exclusively towards green projects⁴. Nonetheless, the green bond market has experienced an unprecedented boom in recent years. Typically, the European Investment Bank is credited with the inception of the green bond market marked by their first-time issuance of this financial innovation in 2007. It was not until 2013 that the Swedish property company Vasakronan established the corporate green bond market subsegment (Nassiry, 2018).

Albeit still small in size in comparison to the conventional bond market, the market for labelled green bonds has experienced rapid growth since its emergence⁵. Whilst the lack of a standardised regulatory framework for green bonds impedes the exact quantification of the green bond market size, the World Bank Group (2023) estimates global issuance of GSSSB⁶ bonds until Q4 2022 at approximately USD 3.8 tn, thereof USD 2.2 tn issued as green bonds

³ The EU Taxonomy is a green classification scheme enacted by the European Commission to evaluate the environmental sustainability of specific economic activities (European Commission, 2022).

⁴ I.e., Larcker and Watts (2020) find underwriting fees for green bonds to be 10% higher than for conventional bonds; CBI (2023d) charges 1/10th bps of the bond issuance amount for certification for use of proceeds.

⁵ Appendix 1 contains a more comprehensive numerical and visual representation of the green bond market.

⁶ GSSSB refers to green, social, sustainable, and sustainability-linked bonds.

(CBI, 2023b). Based on these figures, the OECD (2022) sets the global GSSSB bond issuance CAGR at 80% since 2014 and S&P (2023) forecasts GSSSB issuance to amount to between USD 900 bn and 1 tn in 2023, thus accounting for roughly 14% of expected global bond issuance. In addition, CBI (2021) estimates the size of the unlabelled green bond market, which is not captured in the aforementioned estimates, to stand at another USD 0.9 tn approximately.

3. LITERATURE REVIEW

3.1 Bond Pricing

As with any other security, the theoretical fair price of a (green) bond is the present value of its expected future cash flows. The appropriate discount rates are usually determined in relation to a benchmark, such as a government security in the same currency and with similar maturity, to which an appropriate yield spread is added. The benchmark rate is often referred to as the risk-free rate given the issuing government's taxation power and monetary monopoly. It "reflects the credit risk of the economy of the government that has issued it" (KPMG UK, 2020). The yield spread on top of this risk-free rate reflects the respective security's idiosyncratic risk and market conditions. Asset pricing models attempt to quantify this yield spread to determine an asset's fair value (Bodie et al., 2008). The deviation of actual prices and yields from those predicted by pricing models is referred to as *abnormality*. The persistent observability of such an empirical pattern of abnormal returns is referred to as a *pricing anomaly* and can come in the form of a premium or a discount.

Arbitrage theory and standard asset pricing models assume for securities with identical risk-return profiles to be priced identically. Accordingly, a systematic price differential between non-green and green securities appears nonsensical if issued by the same entity since they are subject to the same market and credit risk. The existence of a greenium could imply investors' willingness to forego returns in exchange for non-fungible, non-pecuniary societal benefits and would thereby challenge traditional asset pricing theories (Larcker and Watts, 2020).

3.2 Empirical evidence on the green bond premium

Since the inception of the green bond market, research has been undertaken to investigate the pricing structure of green bonds, especially compared to their vanilla correspondents. A growing body of research endeavours to substantiate anecdotal evidence of a pricing differential between green and otherwise identical conventional bonds. These greenium studies have long been constrained by the limited availability of green bond data given the novelty of this financial innovation and the comparatively small, yet rapidly growing green bond market size. As a result, findings remain largely inconclusive although a great number of studies set out to evidence the existence of a green premium, determine its sign and quantify its magnitude.

3.2.1 Methodologies

The prevailing variation in greenium estimates is partly explicable by the heterogeneity in studies' methodological designs as “the academic debate remains focused on refining a standard methodological approach by which to detect any greenium” (Harrison et al., 2020). Two strands of commonly employed methodologies, namely matching methods and regression analyses, have emerged out of the academic discourse. Yet, even within those methods, the applicable constraints, data samples, control variables and robustness checks vary greatly.

Matching methods. Matching method, also referred to as model-free or direct approach, describes the selection of pairs consisting of two bonds featuring the same or highly similar properties other than their respective greenness. Typically, a number of pre-defined constraints are applied to match a green bond with a conventional bond before arriving at the final sample. In absence of identical conventional bonds, studies might resort to the creation of synthetic bonds out of two conventional bonds as an artificial counterfactual.

Within financial literature, matching methods have been routinely used to identify and create counterfactuals for the estimation of treatment effects, i.e. to measure bond credit risk, volatility and liquidity premia (cf. Crabbe and Turner, 1995; Helwege et al., 2014; Dick-Nielsen

et al., 2012). Matching methodologies allow to determine the impact of a treatment, such as the issuance as a green bond, whilst closely controlling for other factors possibly influencing the bond pricing. Contrary to regressions, matching methods thereby largely avoid omitted variable bias or multicollinearity by directly comparing treated and control bonds, thus eschewing the need for complex statistical assumptions and avoiding the assumption of functional relationships. Nonetheless, every observational study remains subject to the possibility of unobserved correlated omitted variables to some extent.

Regression analysis. Regression analysis represents another prevalent approach to estimate greenium. By employing statistical techniques, the relationship between various factors and bond pricing is modelled. Whether a bond is green is commonly accounted for using a green dummy variable. The approach decomposes yield spreads into risk factors and thereby estimates the sign, size and magnitude of the greenium captured by the coefficient of the green dummy variable. Generalised and ordinary least squares regressions using fixed effects applied to time series data are the most commonly, yet not exclusively employed approaches. Regardless of the choice of model, control variables and data sample, regression analyses must always balance the risk of omitted variable bias and multicollinearity. Including too many regressors risks multicollinearity as variables initially assumed to be independent become correlated. Conversely, omitting relevant variables might lead to estimation biases when fitting a model.

3.2.2 Findings

A systematic literature review by MacAskill et al. (2021) finds “a mixed, although marginally positive consensus [...] among the examined studies” with regard to the existence of a greenium. General ambiguity persists as to greenia in the primary market, with 44% of studies rejecting and 56% of studies corroborating the notion of a primary market greenium. A much broader consensus exists as to secondary market greenia: 70% of examined studies evidence statistically significant secondary market greenia, a further 17% report greenia of no

statistical significance. The remaining 13% find no consistently statistically significant green bond premium in the aftermarket. MacAskill et al. (2021) attribute this general ambiguity of findings to methodological heterogeneity.

Contra. In a widely acknowledged study of the US municipal bond market, Larcker and Watts (2020) conclude that there is no statistically and economically significant pricing differential between green and non-green securities. Utilizing an exact matching methodology that takes into account issuer and issuance characteristics, they match green bonds with comparable conventional bonds of the same issuer. The common occurrence of simultaneous issuances of otherwise identical green and non-green bonds (“twin securities”) by US municipalities predestine the municipal bond market for the empirical analysis of greenia. A negligible green discount of 0.45 bps is evidenced, with the price differential at issue being zero in 85% of matched cases. Any residual greenia are considered to be rendered economically meaningless by higher issuance and compliance costs for green securities. The bias of greenium estimates of other studies is attributed to “methodological design misspecification [...] [leading] to spurious inferences”, specifically criticising the distortions of estimates through the inclusion of callable and synthetic bonds and the neglect of differences in tax treatments.

Flammer (2020) utilizes a similar methodology to conduct the same study on the corporate bond market. Flammer matches green bonds based on similar firm-level characteristics. By doing so, no price differential of economic and statistical significance is found. Flammer thus argues that green bond issuance is signalling “a credible commitment towards the environment”, yet does not offer firms a cheaper source of financing in the form of a greenium.

Both studies substantiate this quantitative approach with qualitative interviews by referencing Chiang’s (2017) survey of market participants which “unanimously” stated their unwillingness to forgo returns in exchange for green benefits. According to Larcker and Watts (2020), “investors view green and non-green securities by the same issuer as almost exact

substitutes” and are “entirely unwilling to sacrifice returns to invest in green securities.”

Pro. Contrarily, the majority of studies corroborate the existence of a yield spread between green and non-green bonds (cf. MacAskill et al., 2021). Yet, even among scholars in favour of the existence of a green premium, there is no clear consensus as to its magnitude and sign.

Comparatively few studies hypothesize that the greenium predominantly assumes **positive values** such as Bachelet et al. (2019) for non-certified corporate green bonds or Karpf and Mandel (2018) for US municipal bonds. Yet, amongst those papers in favour of the existence of a green premium, most studies provide evidence for **negative greenia**, meaning green bonds trade at a premium and, thus, have lower yields compared to their vanilla counterparts.

Primary vs. secondary markets. Gianfrate and Peri (2019) adopt a propensity score matching approach to study European green bonds issued between 2013 and 2017 at issue. They find a statistically significant and robust green premium in the primary market that also persists in the secondary market, albeit less pronounced. Their findings diverge from the conclusions of the majority of studies which generally find primary market greenia to be weaker than their secondary market counterparts (cf. MacAskill et al., 2021; Ehlers and Packer, 2017; Gatti and Florio, 2018; Harrison, 2020). Accounting for this distinction, Harrison et al. (2020) state that primary market auctions are regularly oversubscribed despite often being inaccessible to a large pool of investors. Gianfrate and Peri (2019) further generalise that green bonds are routinely “bought in the primary market by institutional investors and held until maturity. Hence, [...] in practice they are [often] not traded in the secondary market”, thereby amplifying secondary market greenia by exacerbating liquidity conditions and distorting market prices. Only secondary market trading grants access to green securities to a wider range of market participants including retail investors which tend to be less price-sensitive (Larcker and Watts, 2020).

Liquidity. Many greenium papers account for liquidity differences, albeit in different manners.

In their investigation of the effect of liquidity on greenia, Febi et al. (2019) establish

liquidity as a determinant of greenium magnitude and find generally higher liquidity for green bonds compared to their vanilla counterparts. Regarding its temporal variability, a waning effect of liquidity premia on yield spreads is observed and interpreted as a sign of “a growing maturity of green bonds markets”.

Zerbib (2019) refers to the yield differential within matched bond pairs as “the cumulative effect of the liquidity differential and the green bond premium” rather than the greenium itself. Liquidity differences within matched pairs are controlled for using bid-ask spreads as a liquidity proxy. By doing so, a small, albeit statistically significant average green bond yield premium of -2 bps is evidenced and attributed to the benefit of a broader bondholder base. The liquidity regression evidences a weak R^2 close to 1% but the statistical significance of the liquidity proxy coefficient is high suggesting a measurable impact of liquidity conditions on the greenium but a low explanatory power of liquidity for the overall variability in greenia.

Governance. Bachelet et al. (2019) find a negative greenium for third-party verified green corporate bonds. For non-verified corporate bonds, a positive green premium is evidenced and attributed to informational asymmetries and suspicions of greenwashing. This verification premium echoes the findings of Baker et al. (2018) and Fatica et al. (2021) who find greenia to be more pronounced among bonds that are certified by external verifiers. Hyun et al. (2020) posit that the reduction of information asymmetries on greenness through green certifications lowers the environmental risk which, in turn, explains investors’ willingness to pay higher prices. Dorfleitner et al. (2021) refer to this effect as “different shades of green”, wherein the level of credibility of self-labelled green bonds incrementally increases through alignment with a green bond standard and voluntary third-party verification. The verification benefit seems of higher importance for corporate issuers (Kapraun et al., 2021; Bachelet et al., 2019, Fatica et al., 2021) which might indicate a higher perceived credibility of the green claims of sovereign, supranational and municipal emitters even without a green bond certification.

4. METHODOLOGY

4.1 Research Objective and Design

This study's objective is to analyse the temporal variability of the green bond premium.

R1: *Does greenium display temporal variability?*

To investigate this overarching research question, the following auxiliary research questions have already been introduced in the introduction:

R2: *Do green bonds command a greenium?*

R3: *If confirmed, what is the quantifiable magnitude of this greenium?*

In accordance with previously published works on this subject, the term *greenium* hereby refers to the excess yield on the green bond that is attributable to its green characteristic:

$$\Delta y_{i,t} = y_{GB} - y_{CB} \quad (1)$$

with $\Delta y_{i,t}$ as the spread between the yield of a green (y_{GB}) and a comparable vanilla bond (y_{CB}).

The heterogeneity of methodologies by which to detect such greenium utilized in previous studies has been elaborately discussed in the literature review. Built on this analysis of prior methodological approaches, an optimised matching procedure is developed to pair up green bonds with comparable conventional bonds. A fixed-effects panel regression model will then be employed to estimate the green bond premium whilst accounting for liquidity differences. To identify patterns and trends of temporal variability, the evolution of regression outcomes will then be analysed on a monthly, quarterly and annual basis.

4.2 Data Collection and Cleaning

The financial data provider Refinitiv Workspace (formerly Eikon) is used to retrieve bond characteristics as well as their corresponding market and trading data. Cross-sectional bond data is sourced from the Refinitiv Fixed Income Search tool for both green and conventional bonds. As part of the data collection process, the imposition of various constraints and filters ensures the suitability of the retrieved dataset and the robustness of the analysis built on it. The applied

constraints and resultant reduction in sample size are documented in Table 1 along with their rationales. The final dataset compiles data as to 1,219 green and 90,290 conventional bonds.

Table 1: Data cleaning procedure.

Criterion	Green Bond	Conventional Bonds
Full universe	6,966	976,580
Include: Domiciled in US, CN, FR, DE, UK¹⁾	2,285	276,371
Exclude: Callable and convertible bonds²⁾	1,797	216,047
Include: Fixed or zero coupon²⁾	1,662	183,747
Exclude: Issued before 2007³⁾	1,662	180,745
Exclude: Issued after 2022	1,219	90,290
Final sample	1,219	90,290

¹⁾ To ensure sufficiently large sample sizes and robust results, only the five biggest green bond markets are included (US, CN, FR, DE, UK).

²⁾ The different impacts of embedded options and varying coupon structures on bond pricing disable comparison and, thus, warrant exclusion.

³⁾ In accordance with the green bond market genesis in 2007, bonds issued before 2007 were excluded.

For bonds successfully matched, secondary market time series data in the form of daily observations for ask prices, bid prices and ask yields covering the period between January 2007 and December 2022 is sourced separately from Refinitiv using the Eikon Data API for Python.

Both the cross-sectional and the time series datasets are combined into two-dimensional panel data which will be utilized for the regressions performed in section 4.4.

4.3 Matching Method

This study employs an exact matching method to pair up green bonds with comparable conventional bonds. The matching criteria are defined in Table 2. The matching constraints applied are in line with prior research, albeit often more strictly chosen. The majority of the qualitative variables require an exact match. Quantitative variables are mostly afforded a narrowly defined tolerance around the respective green bond's characteristic due to the impossibility of finding bond pairs exhibiting the exact same econometric properties. Importantly, and contrarily to many methodological approaches of prior studies, matched bonds are required to be issued by the same entity, thereby controlling for a multitude of issuer characteristics including issuer type, domicile, credit rating and economic sector.

Table 2: Matching criteria.

Criterion	Constraint
ISIN	Different
Issuer <i>therefore: issuer type, domicile, credit rating, domicile, etc.</i>	Same <i>Same</i>
Currency	Same
Coupon Type	Same
Seniority	Similar
Maturity	+/- 1 year
Issue Date	+/- 1 year
Issue Amount	+/- 25%

In cases of multiple conventional bonds being an eligible match for a green bond, the closest match was identified using a nearest neighbour algorithm rather than including all matches in the forthcoming regression analysis. This approach was adopted to prevent conceivable distortions stemming from the overrepresentation of singular green bonds in the sample through the inclusion of multiple matches for the same green bond.

4.4 Liquidity Neutralisation

Although the increasing effect of liquidity risk on bond yields is well-researched, a number of greenium studies fail to control for liquidity differences (cf. Baker et al., 2018; Flammer, 2020; Gianfrate and Peri, 2019). If accounted for, liquidity is typically controlled for using one of two methods in the context of greenium detection.

Where no trading data is available, comparable issue sizes of green and vanilla bonds are mandated to control for liquidity. The imposition of this constraint is based on empirical evidence of a positive correlation between issue size and liquidity (Fisher, 1959; Helwege et al., 2014; Crabbe and Turner, 1995). As per the matching constraints laid out in Table 2, the issue amounts of matched pairs shall differ by no more than 25% for the purpose of this study.

In acknowledgement of the limitations of this naïve assumption, where available, liquidity proxies based on trading data are frequently used instead. As the time series data used for this study comprises both, bid and ask prices, the daily difference in bid-ask spreads of green and matched conventional bonds is constructed as a liquidity proxy ($\Delta L_{i,t}$):

$$\Delta L_{i,t} = (Bid_{Green} - Ask_{Green})_{i,t} - (Bid_{Con} - Ask_{Con})_{i,t} \quad (2)$$

Inspired by Zerbib (2019), a fixed-effects panel regression model is then employed to account for any residual liquidity differences not yet captured by the issue size constraint. The green bond premium is determined in accordance with the following regression model:

$$\Delta\tilde{y}_{i,t} = p_i + \beta_1\Delta L_{i,t} + \varepsilon_{i,t} \quad (3)$$

where $\Delta\tilde{y}_{i,t}$ is the daily yield spread between green and conventional bond. The coefficient β_1 indicates the effect of residual liquidity differences ($\Delta L_{i,t}$), measured by the difference in respective daily bid-ask spreads defined in equation (2), on the yield spread. The coefficient of the intercept (p_i) reflects the magnitude of the liquidity-adjusted green bond premium, i.e. the baseline green bond premium estimate when there is no difference in liquidity conditions.

4.5 Methodology Justification and Enhancements to Prior Methodologies

Matching method. Much of accounting and finance research is conducted in observational as opposed to experimental settings where real-world financial data is analysed rather than actively manipulated. In such non-experimental settings, attributing observed differences to the treatment itself, rather than other factors, proves challenging for researchers because simplistic regression techniques could fail to adequately address distortions caused by confounding variables, causal inference and selection biases. Through matching methods, researchers aim to mitigate such distortions by carefully pairing treated and control units on the basis of similar observable characteristics before analysing differences between control and treatment groups (Tucker, 2011; Li and Zhao, 2003). Given their effectiveness in isolating the treatment effect, matching methods have advanced as the methodological best practice in greenium detection within the empirical literature. To leverage this methodological advantage into even more robust results, matching criteria for this study are often much stricter than in prior studies.

Bond synthetisation. Previous studies have routinely resorted to the creation of synthetic conventional bonds as counterfactuals to artificially increase their sample sizes (cf. Bachelet et al., 2019). The multi-step process of intra- or extrapolating such synthetic bonds as well as their

econometric properties has been criticized as prone to distortions (cf. Larcker and Watts, 2020). Due to relatively superior data availability, this study abstains from the inclusion of synthetic bonds as its raw final sample size of matched bond pairs without synthetisation exceeds those of most prior studies that utilise synthetic bonds.

4.6 Limitations of Methodological Approach

There are multiple generally acknowledged limitations shared by most greenium studies.

Bond prices. Most notably, bond pricing data might not accurately reflect the underlying fair value of debt securities due to infrequent trading activity in the bond market. When prices do not accurately capture supply and demand dynamics, this impedes the interpretability of pricing differentials as indicators of investors' willingness to pay a premium for the environmental benefit of their investment.

Data availability. The nascent nature and size of the green bond market further limit conclusions derived from greenium studies. The limited data availability is further exacerbated by the successive reduction in sample size as a result of data collection and bond-matching procedures. Whilst the relative scarcity of green bond data significantly impaired the informative value of early longitudinal studies, the rapid growth of the green bond market segment in recent years allows more recent investigations to sketch a more comprehensive view onto green premia due to an increase in sample sizes as a result of superior data availability. Although the utilization of a relatively larger sample size helps mitigate the impact of the successive reductions in sample size during the various stages of the analysis, it is imperative to acknowledge the potentially distorting impact on the sample randomness of this reduction.

5. FINDINGS AND DISCUSSION

This section presents the empirical results of the matching method and regression models defined in section 4. Findings will be presented and discussed following the structure of research questions established prior before being reconciled with prior literature.

5.1 Matching Method Outcomes

Out of the raw sample containing 1,219 green bonds and 90,290 conventional bonds, the matching method pairs up 497 green bonds (or 40.77%) with counterfactual conventional bonds in accordance with the matching constraints defined in section 4.3. The bonds without an eligible match are consequently dropped from the set of observations (cf. appendix 2).

5.2 Existence of Greenium

During the market data retrieval process, further observations had to be dropped for 225 pairs due to the unavailability of data for these pairs on Refinitiv Workspace. Sufficient market data was retrieved for the remaining 272 bond pairs. Based on the daily observations from those bond pairs, the individual yield spread and liquidity-adjusted greenium of each of those bond pairs are determined using the calculation and regression model defined in equation (1) and (3) respectively. Aggregate yield spread and greenium estimates for the entire final sample are then calculated for a portfolio of equal weights as well as an issue size-weighted portfolio where bond pairs are weighted on the basis of the issued volume of their green bond component.

Equal-weighted portfolio. The mean yield spread computed for the portfolio of equal weights is equal to -0.2 bps (median: +0.9 bps) indicating that the average yield of green bonds in the final sample is -0.2 bps lower than that of its matched conventional bond. In line with Zerbib (2019), this yield spread is viewed as “the cumulative effect of the liquidity differential and the green bond premium”. To estimate the green premium, the liquidity regression model defined in equation (3) is hence fitted to control for residual liquidity.

As can be inferred from the liquidity regression outcome in appendix 3, the mean liquidity-adjusted green bond premium in the overall sample is equal to +1.1 bps. Despite controlling for issue size as part of the matching constraints already, the residual liquidity differences still explain approximately 13% of the variation in greenium estimates according to the model’s R^2 . The liquidity proxy coefficient indicates that a one basis point increase in the bid-ask spread

difference between green and conventional bond will result in an increase of 0.93 percentage points in the yield spread between green and conventional bonds. The coefficient for the liquidity proxy is highly statistically significant at the 1% level. However, the coefficient of the intercept is not with a p-value of 0.67. The liquidity regression does thus not provide strong evidence to suggest that there is a consistently nonzero green bond premium.

Issue size-weighted portfolio. As the statistical insignificance and positive sign of the intercepts conflict with the majority of secondary market greenium studies, this finding warrants further investigation. So far, greenium estimates are calculated for a portfolio of equal-weighted 272 bond pairs. However, an issue size-weighted portfolio of bond pairs reflects market conditions more accurately and would, thus, provide a more accurate greenium estimate.

By weighing greenium observations based on their issue volume, a mean yield spread of approximately -1.2 bps is calculated with the median difference being close to 0 bps. The liquidity-based regression model yields an issue size-weighted and liquidity-adjusted greenium estimate of -0.1 bps for the overall sample. The corresponding p-value of the intercept is equal to 0.99 and thus still highly statistically insignificant. With an R^2 of 8.2%, the explanatory power of the model for the yield spread variability is slightly lower for the issue size-weighted portfolio than for the portfolio of equal weights.

For both portfolios, the yield spread calculations and regression model results provide overwhelmingly conclusive evidence for the nonexistence of a consistently nonzero greenium in the overall sample when controlling for liquidity. At all conventional significance levels, the p-values associated with the intercept indicate failure to reject the implicit null hypothesis that the greenium does not exhibit statistically significant differences from zero.

5.3 Robustness Checks

Although no greenium could be established for the entirety of the sample, it cannot be ruled out that certain bond and/or emitter properties potentially influence the presence of a

greenium. As laid out in the descriptive statistics of the matched bond pairs, the final sample of matches exhibits great heterogeneity. This allows for the subdivision of the final sample into subsamples based on issuer and issuance characteristics (issuance currency, country of issue, bond grade amongst others) so as to explore subgroup greenia. The greenium estimates for the subgroups are summarized in appendix 3.2 and serve as a robustness check of prior results.

Remarkably, no subgroup greenium estimate appears statistically or economically significant. Estimates assume both positive and negative values, yet very closely centre around 0 with their corresponding p-values above all conventional significance levels.

5.4 Temporal Variability of Greenium

To analyse the temporal variability of green bond premium estimates, the sample is dissected temporally to explore how estimates evolve over time (cf. appendix 4).

The matched sample contains time series data spanning from 2017 to 2022 upon the basis of which the yield spread as well as the liquidity-adjusted green bond premium and its corresponding p-values are determined on a daily basis. Daily observations are then transformed into monthly, quarterly and yearly aggregates so as to illustrate the fluctuation of greenium estimates over time. Temporal greenium estimates yielded by this process remain statistically insignificant and centre around zero with their amplitude visibly narrowing as the number of observations increases. Whilst the magnitude expectedly contracts gradually, the underlying premise of this thesis – the existence of a greenium – must ultimately be rejected.

5.5 Reconciliation with the Empirical Greenium Literature

This study does not find conclusive evidence for a consistently observable and statistically as well as economically significant green bond premium. This applies to the entirety of the sample as well as to subgroups and across time. Whilst this finding is consistent with traditional pricing frameworks and theories as well as selected greenium studies, it does contradict the majority of empirical studies investigating the secondary market greenium.

a) Methodological Juxtaposition

It is first endeavoured to rationalise this difference in findings on a methodological level.

Matching constraints. The matching method is identified as the most likely possible cause for the divergence of findings from prior literature: This study only matches green and conventional bonds issued by the same entity, thereby effectively controlling for unobservable issuer-specific pricing determinants. Contrarily, many studies in favour of greenium allow for the matching of bonds from different issuers which they attempt to compensate for by introducing a variety of issuer-specific constraints to the matching procedure (cf. Flammer, 2020; Li et al., 2022). Thereby, those greenium estimates are more susceptible to issuer-specific noise and, thus, less robust than results yielded by the matching method utilised in this study.

Bond synthetisation. Contingent on the applied methodological approach, the interpolation and extrapolation of the yield of a synthetic counterfactual based on the characteristics of two existing conventional bonds mostly assumes a linear relationship between yields and maturities. Although this is a generally reasonable assumption in a constrained environment, it introduces the possibility of poorly estimated counterfactual yields into studies when yield curves assume non-linear shapes. This study avoids the possibility of introducing this common synthetisation bias by only matching green with existing conventional bonds.

Data availability. Often, prior studies were forced to resort to the aforementioned more lenient matching constraints and the creation of synthesised bonds as a result of limited data availability to achieve a workable sample size. As the green bond market matures, these methodological concessions are rendered obsolete by superior data availability due to the rapid expansion of the global green bond market. These relatively greater sample sizes also increases the accuracy and reliability of this study.

b) Qualitative substantiation

Upon methodological justification of this study's findings, a causal rationale shall be provided that reconciles this study's findings with the dissenting majority opinion.

Information asymmetries. Exposure to environmental risks has been found to have a detrimental impact on both, equity and debt cost of capital (Chava, 2014; Dhaliwal et al., 2011; Ghoul et al., 2011). Environmentally friendly corporate behaviour could materialise in a reduction of risk that would justify a lower cost of capital as environmental compliance lowers environmental risk, reputational risk and compliance risk with regards to both, current and future green regulations. Investors, however, might lack sufficient information to distinguish actual green practices with positive risk implications that would justify lower yields from instances of greenwashing. By virtue of their position, emitters possess privileged information as to their environmental credentials. The resultant potential for mistrust of this principal-agent problem might deter investors from investing, thereby causing firms to suffer from suboptimal cost of capital (Caramichael and Rapp, 2022).

Signalling effect. In an attempt to counter such greenwashing suspicions, issuers of green bonds credibly signal their environmental commitment by tolerating extensive reporting requirements, constrained proceed usage, the acceptance of higher issuance costs as well as the allocation of sizeable financial and managerial resources to green projects. This compliance with additional reporting and disclosure requirements lowers informational asymmetries, thereby reducing reputational risk. If green pledges materialise in eco-friendly behaviour, possibly through projects financed by green bonds, issuers lower their environmental and compliance risk. If communicated to investors in a credible manner, those risk reductions can translate into security pricing through lower cost of capital. On the demand side, this signal can further permeate into asset pricing through the widening effect on issuers' investor base which studies have attributed to green bond issuance (Zerbib, 2019; Tang and Zhang, 2020).

Green halo effect. Contrary to the notion of a greenium which conceptually limits such green pricing benefits to green securities only, the above-discussed cost of capital mechanisms would likely affect all securities from green bond issuers, not just its green bonds. Specifically,

the credible communication of risk reductions and widening effect on the investor base are likely to also extend to non-green securities of green bond issuers. Yet, current greenium research often neglects the potential of such issuer-wide externalities of green bond issuance in favour of a theoretical greenium that captures the entire pricing benefit.

The possible phenomenon of an appreciation of *all* outstanding securities, both debt and equity, as a result of green bond issuance has been dubbed the green halo effect. The effect, first popularised within the green finance discourse by NatWest Markets researcher Krebbers (2019a; 2019b), does not negate the existence of a greenium. Yet, it further complicates the quantification of greenium as it necessitates the isolation of the green bond premium from possible issuer-wide externalities of green bond issuance.

Testing alternative hypothesis. Assuming the presence of a green halo effect, a pricing differential between green and vanilla bonds from the *same* issuer would not necessarily exist. The positive impact of green bond issuance on asset prices would be captured by all securities of that issuer to the same or possibly varying degrees. The testable hypothesis implied in this assumption is that a matching method that matches green and conventional bonds from the same issuer (“issuer-specific matching”) may not yield a greenium as the issuance of green bonds exerts downward pressure on the entire bond curve of that issuer. Yet, an “issuer-unspecific” matching method that matches green bonds with conventional bonds from a comparable issuer that historically has *not* issued any green bonds might evidence a price differential if the green halo effect holds.

Table 3: *Additional matching criteria for issuer-unspecific matching.*

Criterion	Constraint
Issuer	<i>Different</i>
Issuer Type	Same
Economic Sector	Same
Credit Rating	Same
Domicile	Same

To test this, conventional bonds issued by entities that have previously issued green bonds are excluded from the sample. As displayed in Table 3, the matching method is amended to control for a variety of issuer characteristics instead of matching securities from the same issuer. Ultimately, the liquidity-adjusted greenium for the modified sample is re-estimated.

Indeed, the first-stage regression outcomes for this issuer-unspecific matching method exhibit much higher liquidity-adjusted greenium results relative to previous results utilizing the issuer-specific matching approach: The issuer-unspecific, liquidity-adjusted greenium estimate is equal to -23.16 bps for the equal-weighted portfolio (vs. -1.3 bps for the issuer-specific matched greenium estimate) and -26.34 bps (vs. 0 bps) for the issue size-weighted portfolio.

Most interestingly, the coefficients for the intercept reflecting the greenium are statistically significant for the issuer-unspecific estimates at a 5% significance level. This statistical significance is persistent across subgroups and time and stands in contrast to the significance of the estimates of the issuer-specific approach that were deemed highly statistically insignificant.

Although this is insufficient to confirm the presence of a green halo effect, these results are consistent with two priorly formulated hypotheses: (1) A more lenient, issuer-unspecific matching approach is more likely to deliver greenium estimates of deceiving statistical and economic significance; (2) Green bond issuance does not only lower the yield of green bonds but also conventional yields of the green bond issuer relative to those of comparable conventional bond issues from emitters that have not engaged in green bond issuance.

Overall, this finding provides suggestive evidence that the green halo effect offers a more promising trajectory for future research than the elusive green bond premium whilst exposing shortcomings of prior methodological greenium detection approaches. The absence of a greenium for bonds of the same issuer in combination with the presence of an issuer-unspecific green yield differential advocates for a much broader role of green bond issuance in asset pricing than implied by the notion of a green bond premium which could not be evidenced within this study.

6. CONCLUSION

The objective of this thesis is to analyse the temporal variability of the green bond premium. To do so, a rigorous matching method is developed and applied to pair up green with comparable conventional bonds. A fixed-effects panel regression model is employed to isolate the effect of residual liquidity from the green bond premium within daily yield spreads.

In doing so, no green bond premium of statistical or economic significance could be evidenced. This finding is in line with traditional asset pricing theory and holds true across subgroups and time. The implicit null hypothesis that the yield spread between green and comparable conventional bonds is different from zero is consequently rejected.

This divergence in findings from what is developing to be the consensus opinion in the greenium discourse is attributed to methodological differences. Specifically, superior data availability, more rigorous matching constraints and the abstention from bond synthetisation mitigate the introduction of distorting biases in this study that prior methodological approaches have been exposed to.

Through the exclusion of conventional bond issuers with green bond issues from the final sample, it is showcased how a more lenient matching approach produces estimates of deceiving statistical and economic significance reminiscent of those of prior research.

While the existence of a green bond premium is consequently rejected, the empirical results from this second, issuer-unspecific matching approach point towards a broader role of green bond issuance in the overall reduction of cost of capital. Concretely, investors do not appear willing to forego returns in exchange for non-pecuniary, green benefits. Instead, it is shown how green bond issuance could affect asset prices in an issuer-wide manner by credibly communicating risk reductions and widening the investor base. Further greenium research is therefore recommended to avoid common biases through negligent bond matching as well as to broaden the discourse by incorporating and exploring the possibility of a green halo effect.

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Appendices

Appendix 1: Green bond market overview

Figure 1 - Green Bond Issuance by Market Type

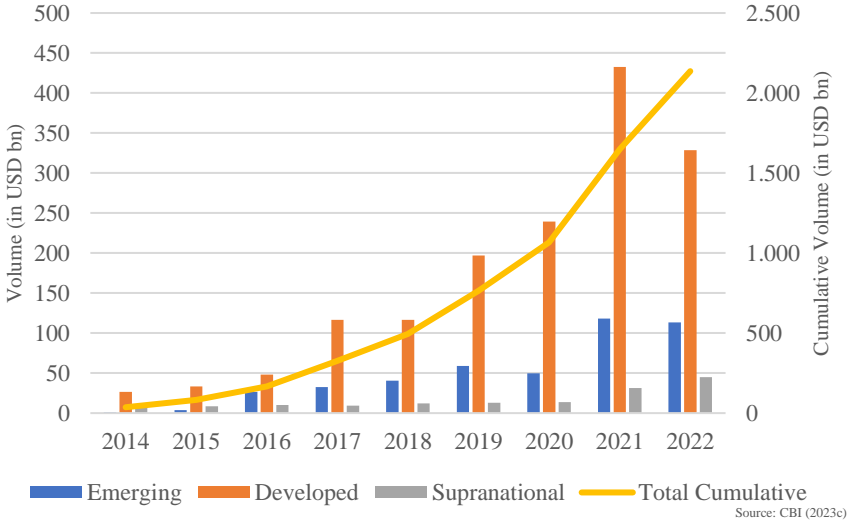


Figure 2 - Green Bond Issuance by Region

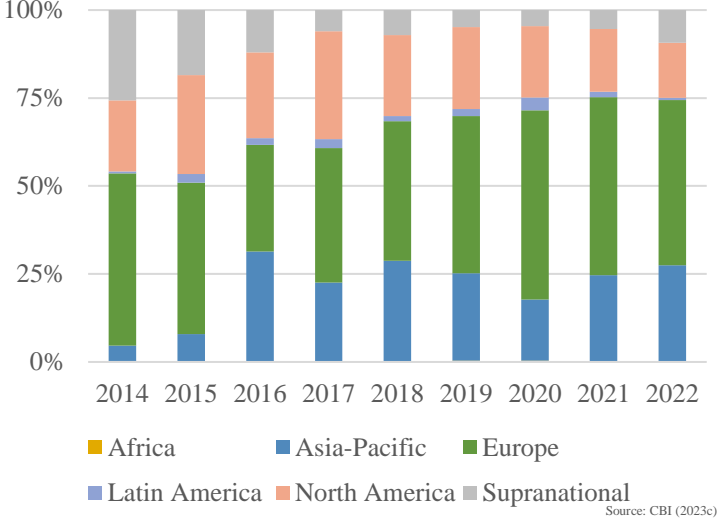


Figure 3 - Green Bond Issuance by Issuer Type

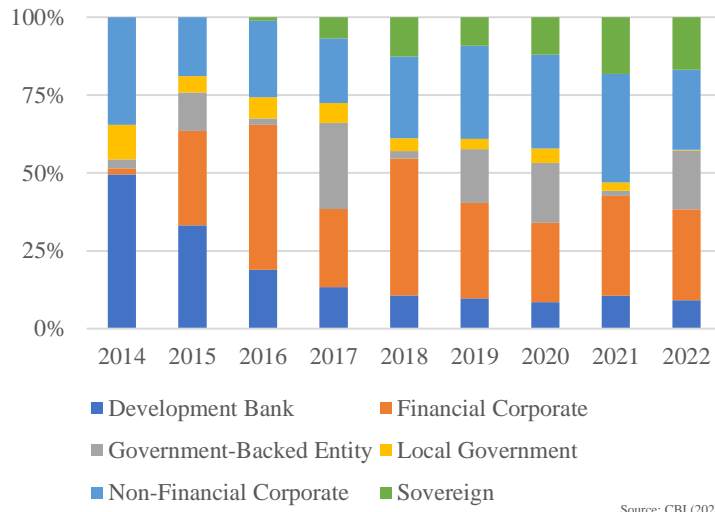


Figure 4 - Green Bond Issuance by Currency

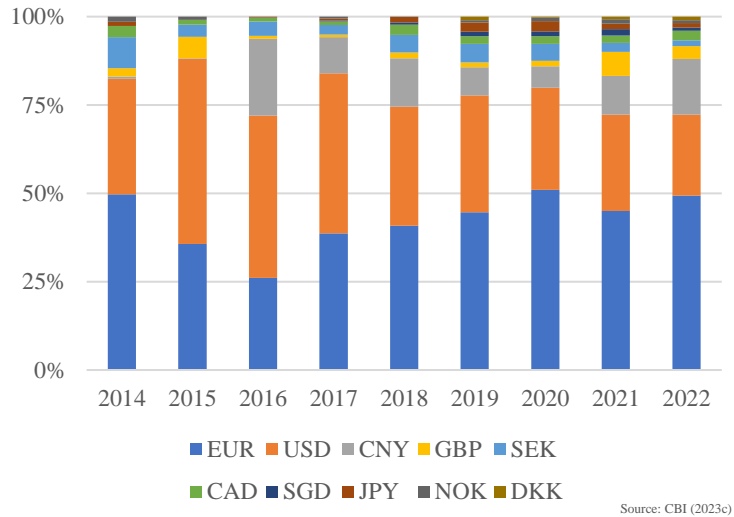
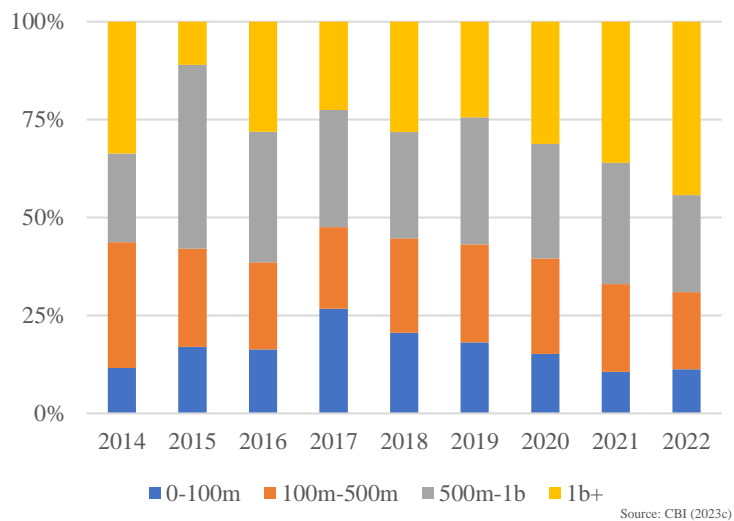


Figure 5 - Green Bond Issuance by Deal Size



Appendix 2: Descriptive statistics as to final sample of matched pairs

Table 4: *Reduction in sample size throughout data selection, cleaning retrieval and matching procedure.*

Category	Subcategory	green bonds	con bonds	Σ	matched sample	final sample
Total		1.219	90.290	91.509	497	271
Country of Issue	USA	185	52.397	52.582	32	23
	China	592	23.210	23.802	147	135
	France	105	2.563	2.668	25	18
	Germany	333	11.781	12.114	292	94
	UK	4	339	343	1	1
Currency	USD	174	52.422	52.596	30	21
	RBP	592	23.227	23.819	147	135
	EUR	434	13.777	14.211	316	112
	GBP	4	337	341	1	1
	others	15	527	542	3	2
Issue Amount (USD)	small (< 85m)	426	35.737	36.163	139	63
	medium (>85m, <125m)	206	30.557	30.763	124	51
	large (>125)	587	23.996	24.583	234	157
Coupon Type	Fixed Coupon	1.200	55.306	56.506	492	271
	Zero Coupon	19	34.984	35.003	5	5
Coupon Rate	0	19	34.984	35.003	12	5
	low (<5%)	545	47.603	48.148	462	251
	high (\geq 5%)	655	7.703	8.358	23	20
Maturity	2022 and earlier	0	1.285	1.285	0	0
	2023 till 2025	541	48.725	49.266	176	130
	2026 and after	678	40.280	40.958	321	141
Issue Date	2022 & 2021	803	49.438	50.241	342	188
	2020 & 2019	265	21.660	21.925	128	65
	2018 & 2017	60	8.910	8.970	17	12
	2016 and earlier	91	10.282	10.373	10	6

Appendix 3: Regression outcomes

3.1 Yield spreads and greenia overview

Table 5: *Yield spreads of matched green and conventional bond pairs in final dataset.*

	Yield Spread								
	Min	1st Quart	Mean	Median	3rd Quart	Max	std	p	t
Equal-weighted portfolio	-3.164	-0.095	-0.002	0.009	0.142	2.529			
Issue size-weighted portfolio	-8.637	-0.077	-0.012	0.001	0.069	7.669			

Table 6: *Issuer-specific, liquidity-adjusted greenium estimates for final sample.*

	Min	1st Quart	Mean	Median	3rd Quart	Max	std	p	t
Equal-weighted portfolio	-1.428	-0.039	-0.003	0.01	0.055	0.796	0.026	0.674	0.421
Issue size-weighted portfolio	-0.986	-0.082	-0.013	0.0	0.075	1.159	0.050	0.993	-0.009

3.2 Subgroup analysis of liquidity-adjusted and issue-size weighted greenium estimates

The liquidity-adjusted greenium estimates in Table 7 are based on the issue size-weighted portfolio of matches that were paired up using the issuer-specific matching method:

Table 7: *Liquidity-adjusted and issue-size weighted greenium estimates.*

Category	Subcategory	# matches	Min	1st Quart	Mean	Median	3rd Quart	Max	std	t	p
Total		271	-0.986	-0.082	-0.013	-0.0	0.075	1.159	0.050	-0.009	0.993
Country of Issue	USA	23	-0.26	-0.031	-0.013	-0.0	0.022	0.074	0.346	1.128	0.272
	China	135	-0.472	-0.073	-0.01	-0.011	0.064	0.372	0.013	-0.403	0.687
	France	18	-0.304	-0.006	0.062	0.047	0.086	0.535	0.169	-0.836	0.416
	Germany	94	-0.986	-0.194	-0.037	0.01	0.131	1.159	0.120	-0.490	0.626
Currency	USD	21	-0.26	-0.034	-0.015	-0.004	0.022	0.074	0.383	1.038	0.312
	RBP	135	-0.472	-0.073	-0.01	-0.011	0.064	0.372	0.014	-0.403	0.687
	EUR	112	-0.986	-0.162	-0.019	0.021	0.126	1.159	0.102	-0.904	-0.295
Issue Amount	small (< 85m)	63	-0.472	-0.012	0.052	0.03	0.117	0.627	0.007	1.151	0.255
	medium (>85mn, <125mn)	51	-0.572	-0.175	-0.039	-0.014	0.049	1.159	0.021	0.179	0.859
	large (>125mn)	157	-0.986	-0.092	-0.026	-0.007	0.057	0.643	0.080	0.231	0.818
Bond Grade	Investment Grade	72	-0.767	-0.058	0.01	0.018	0.063	0.643	0.162	-0.025	0.980
	High Yield	199	-0.986	-0.107	-0.022	-0.005	0.079	1.159	0.015	-1.626	0.106
Coupon Rate	0	5	-0.19	-0.172	-0.09	-0.162	0.032	0.043	0.108	0.643	0.566
	low (<5%)	251	-0.986	-0.075	-0.012	-0.0	0.075	1.159	0.054	-0.017	0.987
	high (≥ 5%)	20	-0.261	-0.149	-0.027	-0.024	0.054	0.229	0.057	0.049	0.961
Maturity	2023 till 2025	130	-0.986	-0.093	-0.018	-0.014	0.057	1.159	0.045	-1.220	0.225
	2026 and after	141	-0.913	-0.069	-0.008	0.007	0.096	0.643	0.088	0.541	0.590
Issue Date	2022 & 2021	188	-0.986	-0.092	-0.025	-0.004	0.064	1.159	0.052	-0.212	0.832
	2020 & 2019	65	-0.521	-0.068	0.021	0.015	0.108	0.643	0.149	0.929	0.357
	2018 & 2017	12	-0.261	-0.092	-0.02	-0.02	0.053	0.256	0.179	-1.643	0.131
	2016 and earlier	6	-0.295	-0.016	0.042	-0.001	0.027	0.535	0.028	-2.081	0.106

3.3 Issuer-specific matching approach: equal-weighted portfolio

Table 8: *Liquidity regression results of the issuer-specific, equal-weighted portfolio.*

OLS Regression Results						
Dep. Variable:	yield spread	R-squared:	0.134			
Model:	OLS	Adj. R-squared:	0.131			
Method:	Least Squares	F-statistic:	39.30			
Date:	Tue, 19 Dec 2023	Prob (F-statistic):	1.55e-09			
Time:	21:47:40	Log-Likelihood:	-136.27			
No. Observations:	256	AIC:	276.5			
Df Residuals:	254	BIC:	283.6			
Df Model:	1					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975]
const	0.0109	0.026	0.421	0.674	-0.040	0.062
BASprDiff	0.9250	0.148	6.269	0.000	0.634	1.216
Omnibus:	137.279	Durbin-Watson:	2.001			
Prob(Omnibus):	0.000	Jarque-Bera (JB):	1552.274			
Skew:	-1.855	Prob(JB):	0.00			
Kurtosis:	14.478	Cond. No.	5.71			

3.4 Issuer-specific matching approach: issue size-weighted portfolio

Table 9: *Liquidity regression results of the issuer-specific, issue size-weighted portfolio.*

OLS Regression Results						
Dep. Variable:	yield spread	R-squared:	0.082			
Model:	OLS	Adj. R-squared:	0.079			
Method:	Least Squares	F-statistic:	22.79			
Date:	Thu, 14 Dec 2023	Prob (F-statistic):	3.05e-06			
Time:	20:59:50	Log-Likelihood:	-305.87			
No. Observations:	256	AIC:	615.7			
Df Residuals:	254	BIC:	622.8			
Df Model:	1					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975]
const	-0.0005	0.050	-0.009	0.993	-0.099	0.098
BASprDiff	1.3662	0.286	4.774	0.000	0.803	1.930
Omnibus:	122.511	Durbin-Watson:	2.014			
Prob(Omnibus):	0.000	Jarque-Bera (JB):	49892.748			
Skew:	-0.274	Prob(JB):	0.00			
Kurtosis:	71.390	Cond. No.	5.71			

3.5 Issuer-unspecific matching approach: equal-weighted portfolio

Table 10: Liquidity regression results of the issuer-unspecific, equal-weighted portfolio.

OLS Regression Results						
Dep. Variable:	yield spread	R-squared:	0.138			
Model:	OLS	Adj. R-squared:	0.129			
Method:	Least Squares	F-statistic:	15.87			
Date:	Sun, 17 Dec 2023	Prob (F-statistic):	0.000129			
Time:	16:07:03	Log-Likelihood:	-147.17			
No. Observations:	101	AIC:	298.3			
Df Residuals:	99	BIC:	303.6			
Df Model:	1					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975]
const	-0.2316	0.116	-1.989	0.049	-0.463	-0.001
BASprDiff	-1.2908	0.324	-3.984	0.000	-1.934	-0.648
Omnibus:	12.539	Durbin-Watson:	1.532			
Prob(Omnibus):	0.002	Jarque-Bera (JB):	21.130			
Skew:	0.505	Prob(JB):	2.58e-05			
Kurtosis:	5.001	Cond. No.	3.19			

3.6 Issuer-unspecific matching approach: issue size-weighted portfolio

Table 11: Liquidity regression results of the issuer-unspecific, issue size-weighted portfolio.

OLS Regression Results						
Dep. Variable:	yield spread	R-squared:	0.073			
Model:	OLS	Adj. R-squared:	0.063			
Method:	Least Squares	F-statistic:	7.755			
Date:	Sat, 16 Dec 2023	Prob (F-statistic):	0.00642			
Time:	14:44:19	Log-Likelihood:	-140.01			
No. Observations:	101	AIC:	284.0			
Df Residuals:	99	BIC:	289.3			
Df Model:	1					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975]
const	-0.2634	0.108	-2.428	0.017	-0.479	-0.048
BASprDiff	-0.8405	0.302	-2.785	0.006	-1.439	-0.242
Omnibus:	15.931	Durbin-Watson:	1.468			
Prob(Omnibus):	0.000	Jarque-Bera (JB):	23.854			
Skew:	-0.717	Prob(JB):	6.61e-06			
Kurtosis:	4.900	Cond. No.	3.19			

Appendix 4: Temporal variability of greenium estimates

The following visual and numerical representations are based on the issue size-weighted portfolio of matches that were paired up using the issuer-specific matching method:

4.1 Yearly variability of greenium estimates

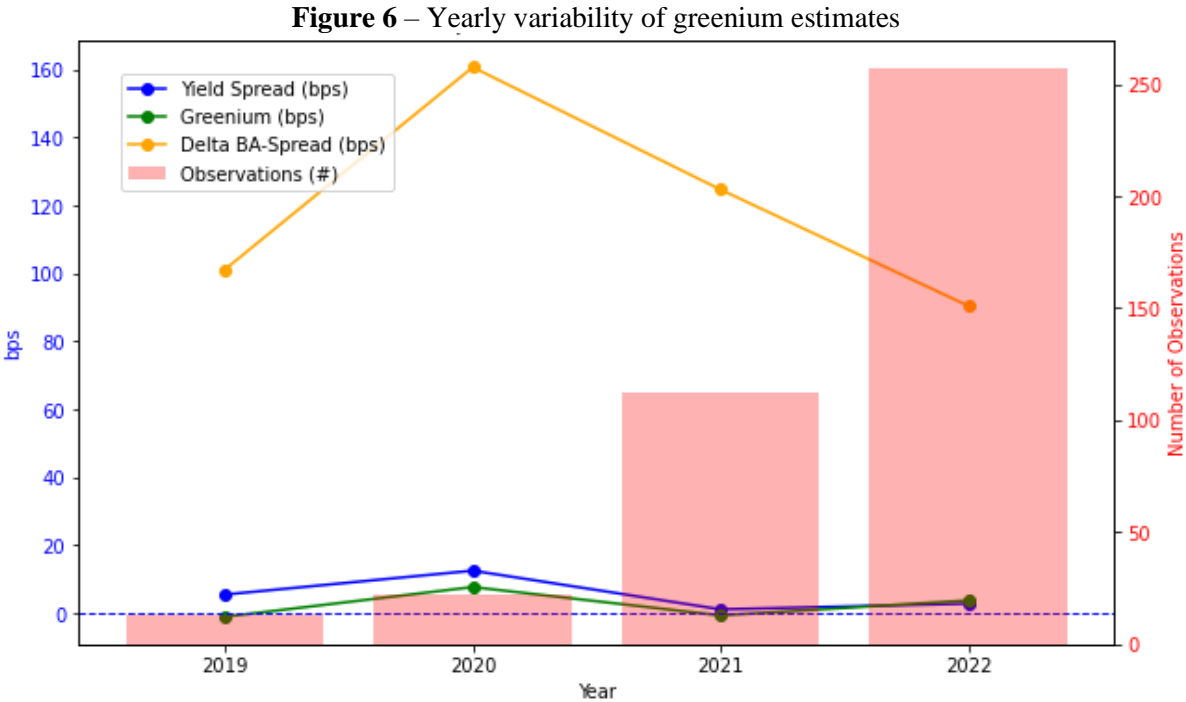


Table 12: Yearly variability of greenium estimates.

year	yield spread (bps)	greenium (bps)	p	coeff_L ¹⁾	p_L ²⁾	# observations
2019	0.055	-0.010	0.912	1.012	0.123	13
2020	0.125	0.077	0.468	1.607	0.055	22
2021	0.011	-0.006	0.879	1.247	0.000	112
2022	0.028	0.038	0.265	0.904	0.000	257

¹⁾coeff_L refers to the coefficient of the liquidity proxy defined in equation (2).

²⁾p_L refers to the p-value associated with the liquidity proxy coefficient.

4.2 Quarterly variability of greenium estimates

Figure 7 – Quarterly variability of greenium estimates

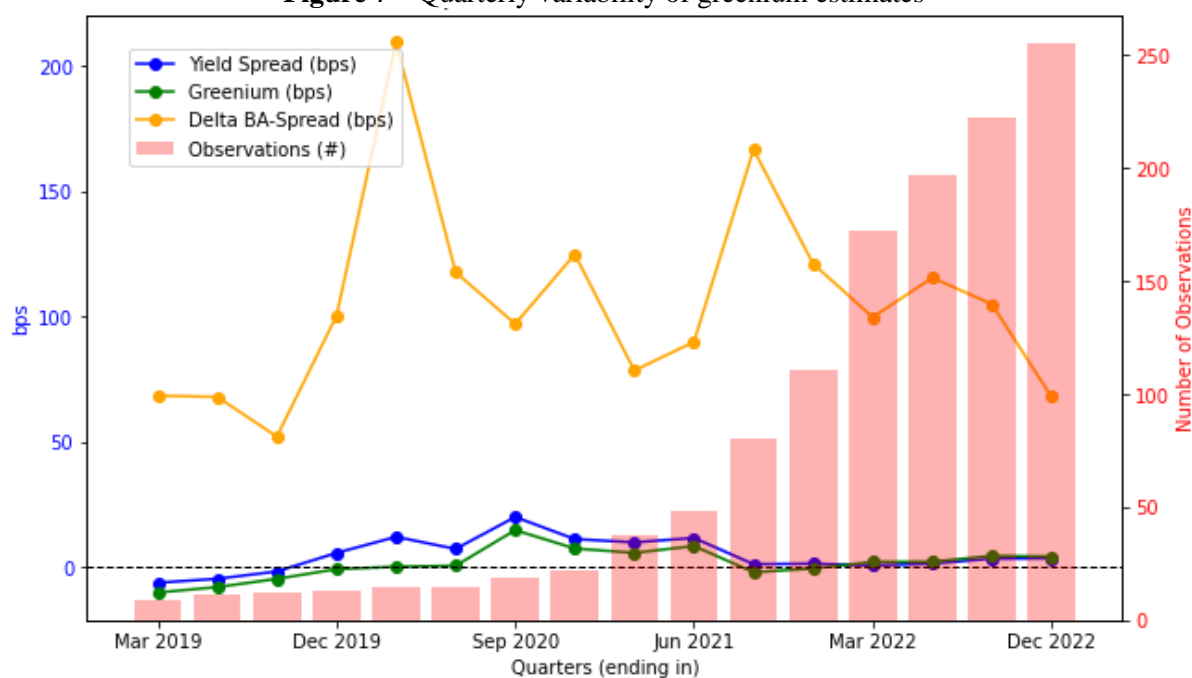


Table 13: Quarterly variability of greenium estimates.

quarter (ending in)	yield spread (bps)	greenium (bps)	p	coeff_L	p_L	# observations
Mar-19	-0.062	-0.101	0.233	0.684	0.188	9
Jun-19	-0.046	-0.079	0.210	0.679	0.117	11
Sep-19	-0.017	-0.047	0.324	0.521	0.113	12
Dec-19	0.057	-0.008	0.935	1.003	0.135	13
Mar-20	0.121	0.002	0.988	2.095	0.023	15
Jun-20	0.073	0.006	0.941	1.177	0.054	15
Sep-20	0.200	0.148	0.182	0.971	0.258	19
Dec-20	0.112	0.075	0.470	1.249	0.119	22
Mar-21	0.099	0.057	0.447	0.785	0.152	38
Jun-21	0.117	0.084	0.148	0.899	0.036	48
Sep-21	0.012	-0.020	0.734	1.667	0.001	80
Dec-21	0.014	-0.005	0.895	1.211	0.000	111
Mar-22	0.007	0.021	0.495	0.998	0.000	172
Jun-22	0.014	0.022	0.489	1.155	0.000	197
Sep-22	0.034	0.045	0.212	1.050	0.000	222
Dec-22	0.035	0.043	0.276	0.680	0.003	255

4.3 Monthly variability of greenium estimates

Figure 8 – Monthly variability of greenium estimates

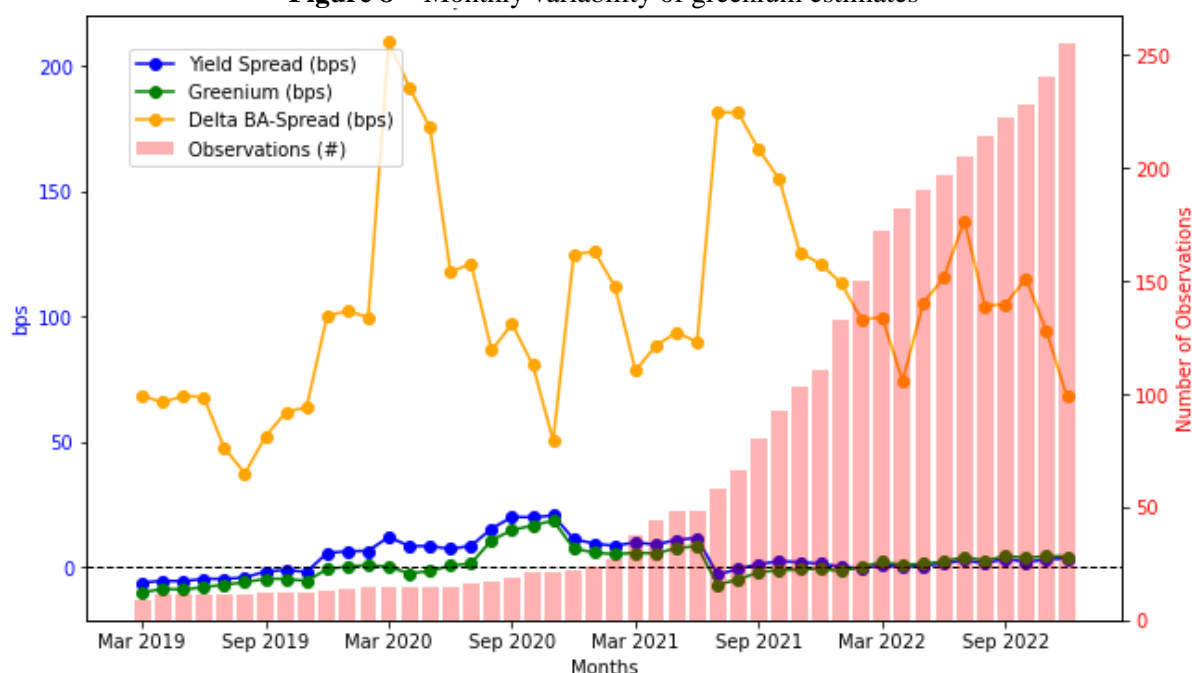


Table 14: Monthly variability of greenium estimates.

month	yield spread (bps)	greenium (bps)	p	coeff_L	p_L	# observations
Mar-19	-0.062	-0.101	0.233	0.684	0.188	9
Apr-19	-0.054	-0.086	0.213	0.658	0.159	11
May-19	-0.056	-0.090	0.187	0.683	0.137	11
Jun-19	-0.046	-0.079	0.210	0.679	0.117	11
Jul-19	-0.047	-0.070	0.195	0.476	0.188	11
Aug-19	-0.041	-0.060	0.207	0.374	0.232	11
Sep-19	-0.017	-0.047	0.324	0.521	0.113	12
Oct-19	-0.011	-0.046	0.420	0.620	0.122	12
Nov-19	-0.019	-0.055	0.358	0.638	0.126	12
Dec-19	0.057	-0.008	0.935	1.003	0.135	13
Jan-20	0.063	0.003	0.976	1.023	0.114	14
Feb-20	0.065	0.008	0.922	0.998	0.118	15
Mar-20	0.121	0.002	0.988	2.095	0.023	15
Apr-20	0.084	-0.025	0.803	1.916	0.017	15
May-20	0.084	-0.015	0.880	1.755	0.029	15
Jun-20	0.073	0.006	0.941	1.177	0.054	15
Jul-20	0.085	0.015	0.840	1.212	0.035	16
Aug-20	0.154	0.108	0.280	0.866	0.249	17
Sep-20	0.200	0.148	0.182	0.971	0.258	19
Oct-20	0.199	0.167	0.114	0.808	0.314	21
Nov-20	0.206	0.186	0.080	0.505	0.526	21
Dec-20	0.112	0.075	0.470	1.249	0.119	22
Jan-21	0.094	0.058	0.552	1.260	0.108	24

Feb-21	0.085	0.052	0.558	1.121	0.127	27
Mar-21	0.099	0.057	0.447	0.785	0.152	38
Apr-21	0.090	0.055	0.393	0.884	0.053	44
May-21	0.109	0.076	0.221	0.937	0.039	48
Jun-21	0.117	0.084	0.148	0.899	0.036	48
Jul-21	-0.030	-0.070	0.416	1.816	0.006	58
Aug-21	-0.006	-0.049	0.510	1.814	0.002	66
Sep-21	0.012	-0.020	0.734	1.667	0.001	80
Oct-21	0.024	-0.012	0.809	1.548	0.000	93
Nov-21	0.020	-0.009	0.839	1.256	0.000	103
Dec-21	0.014	-0.005	0.895	1.211	0.000	111
Jan-22	0.002	-0.016	0.651	1.135	0.000	133
Feb-22	-0.005	0.001	0.969	0.988	0.000	150
Mar-22	0.007	0.021	0.495	0.998	0.000	172
Apr-22	0.001	0.009	0.776	0.743	0.000	182
May-22	0.006	0.014	0.655	1.053	0.000	190
Jun-22	0.014	0.022	0.489	1.155	0.000	197
Jul-22	0.029	0.042	0.228	1.383	0.000	205
Aug-22	0.014	0.025	0.469	1.043	0.000	214
Sep-22	0.034	0.045	0.212	1.050	0.000	222
Oct-22	0.020	0.037	0.354	1.151	0.000	228
Nov-22	0.031	0.044	0.241	0.941	0.000	240
Dec-22	0.035	0.043	0.276	0.680	0.003	255
