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Pricing of Green Bonds: Greenium Dynamics and the Role of Retail Investors

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Abstract

The green bond market has experienced rapid growth in recent years, driven by increasing global awareness of climate change. However, the existence, magnitude and driving forces behind the "greenium" in the secondary market - a price premium associated with green bonds - remain subject to debate. This study investigates the evolution of the greenium in the euro area from 2016 to 2023, encompassing a period of significant macroeconomic shifts, including the COVID-19 pandemic, energy crisis, and the subsequent period of heightened inflation and monetary tightening. Our analysis applies a k-prototypes matching algorithm to construct a closely matched panel of European green and conventional bonds and documents a novel finding that retail investors' demand for green bonds partly drives the greenium. Sensitivity of retail investors' financial conditions to the macroeconomic situation and particularly tighter monetary policy may explain investors' appetite for green bonds and thus the greenium time dynamics. Finally, we confirm investors' preferences for green bonds with higher credibility of both bonds and bond issuers.

Keywords: Green Bonds; Greenium; Retail Investors; Sustainable Finance; Corporate Sustainability

JEL classification: G12, G14, Q50, A56

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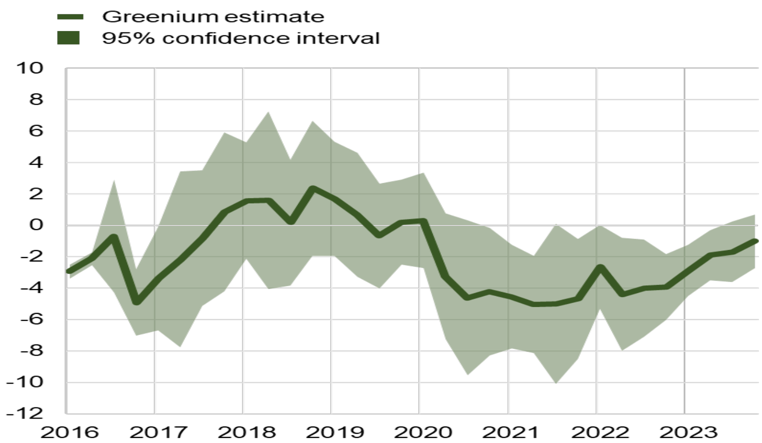
Non-Technical Summary

Green bonds are financial tools designed to fund environmentally friendly projects, such as renewable energy or sustainable infrastructure, to support the shift toward a low-carbon economy. Since 2015, the green bond market has grown rapidly, reaching over USD 2.2 trillion by the end of 2023. However, growth has slowed since 2022 due to challenges like the European energy crisis, rising inflation, and tighter monetary policies.

This study explores the greenium – the tendency for green bonds to have lower spreads compared to similar conventional bonds – in the European secondary market, where green bonds are often seen as more trustworthy due to strong environmental regulations. We analyze how the greenium changes over time, focusing on the period from 2016 to 2023 with significant economic shifts.

Figure 1. Estimated greenium and confidence interval on quarterly subsamples



Note: The Figure shows the estimated coefficient on the green bond dummy for a sample of 984 euro area matched green and conventional bonds between 2016 and 2023.

Using data from the ECB Securities Holding Statistics and Bloomberg, we examine a large dataset of green and conventional bonds issued in the euro area. We focus on bonds defined as green by the widely accepted ICMA Green Bond Principles and use a k-prototypes matching algorithm to construct a closely matched panel of green and conventional bonds.

Our findings suggest that on the full sample from 2016 to 2023, European green bonds generally have a small but significant greenium, averaging about -3.7 basis points, meaning they are slightly cheaper to issue than conventional bonds. Furthermore, this greenium varies over time: it was negligible before 2020, grew stronger from 2020 to early 2022, and weakened again in 2022–2023, reflecting changing economic conditions.

We document that this temporal dynamics is driven by retail investors. In mid-2020, a sharp increase in retail investors' share of green bonds, particularly those issued by banks, explains the rise in economic and statistical significance of greenium. On the other hand, greenium disappears when the demand for these bonds weakens with rising interest rates and worsening economic conditions. On average, green bonds held by retail investors also show a larger greenium of -6.4 bps. Our results corroborate studies relying on survey and choice experiment setups to show that retail investors favor green bonds despite lower return (Aruga (2025), Saravade et al. (2025)).

Finally, we confirm previous findings that investors value more credible green bonds that are either externally reviewed or issued by banks committed to environmental goals, such as members of the UNEP FI. These bonds have a stronger greenium, -4.1 bps for reviewed bonds and -5.7 bps for bonds from committed banks, highlighting the market's preference for trustworthy green investments.

This study adds to the understanding of green bonds by showing how the greenium evolves, the role of retail investors, and the importance of credibility in the European market. These insights highlight the need for clear standards, like the EU Green Bond Standard, to ensure green bonds genuinely contribute to environmental goals and maintain investor trust.

Prix des obligations vertes : dynamique du greenium et rôle des investisseurs particuliers

RÉSUMÉ

Le marché des obligations vertes a connu une croissance rapide ces dernières années, stimulé par une prise de conscience mondiale croissante des changements climatiques. Cependant, l'existence, l'ampleur et les forces motrices derrière le « greenium » – une prime de prix associée aux obligations vertes – sur le marché secondaire restent sujettes à débat. Cette étude examine l'évolution du greenium dans la zone euro de 2016 à 2023, couvrant une période marquée par des bouleversements macroéconomiques importants, notamment la pandémie de COVID-19, la crise énergétique et la période subséquente d'inflation élevée et de resserrement monétaire. Notre analyse applique un algorithme d'appariement k-prototypes pour construire un panel étroitement apparié d'obligations vertes et conventionnelles européennes et documente une découverte : la demande des investisseurs particuliers pour les obligations vertes contribue partiellement au greenium. La sensibilité des conditions financières des investisseurs particuliers à la situation macroéconomique, et en particulier à une politique monétaire plus stricte, pourrait expliquer l'appétit des investisseurs pour les obligations vertes et ainsi la dynamique temporelle du greenium. Enfin, nous confirmons les préférences des investisseurs pour les obligations vertes présentant une crédibilité plus élevée, tant pour les obligations que pour leurs émetteurs.

Mots-clés : obligations vertes, prime verte, investisseurs particuliers, finance durable, durabilité des entreprises

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1 Introduction

Green bonds are sustainable finance instruments that aim to finance environmentally sustainable projects and the transition to a low-carbon economy. The green bond market has shown fast growth since 2015, reaching a size of over USD 2.2 trillion by the end of 2023. However, its growth has slowed down since 2022 following the change in macroeconomic conditions, e.g., the energy crisis in Europe, higher inflation and tightening monetary policy worldwide.

In this paper, we examine the cross-sectional and temporal heterogeneity in the greenium in the secondary market - the negative spread between green and conventional bonds issued by European entities - as observed in Stylised Figure 1. Green bonds issued by European entities are generally seen as more credible due to Europe's strong environmental commitments and often benefit from a greenium compared to other green bonds traded in the secondary market (Kapraun et al. (2021), Caramichael and Rapp (2024)). However, these bonds still exhibit notable temporal and cross-sectional variations.

We contribute to the analysis on green bonds in several aspects. We start by studying the evolution of the greenium from 2016 to 2023, a period covering varying macroeconomic conditions such as the energy crisis and monetary tightening in the euro area; to the best of our knowledge, this period has not been studied yet. Employing proprietary ECB data on securities holdings, we observe that the greenium time dynamics are primarily driven by retail investors that unexpectedly increase their holdings of bank-issued green bonds. We further investigate if macroeconomic factors influence retail investors' demand for green bonds. Finally, we conclude by analysing how much investors value credibility of green bonds themselves and of banks issuing them.

To run the analysis, we construct a database covering all green bonds issued in the euro area from 2016 to 2023 using several datasets. In our study, we use a definition of green bonds provided by the ICMA Green Bond Principles (GBP), which is used by Bloomberg and is overall the most widely used definition in the market. Ehler and Packer (2017) estimate that Bloomberg covers about 80% of the green bond market in 2017. Bloomberg also provides data that allows us to distinguish the quality of greenness depending on whether a green bond has an external review or not. It is important to note that ICMA GBP only recommend external review but do not require it. We complement the data on green bonds with market data on prices and bond characteristics from Bloomberg and the ECB's Centralised Securities Database (CSDB).

Finally, we use Securities Holdings Statistics by Sector (SHSS) to obtain information on holdings of green bonds by investor type at the sector level.

We perform our analysis on a panel dataset with daily data on option-adjusted spreads (OAS). The academic literature tends to use yield spreads to study green bonds and bonds in general; however, industry professionals mostly use bond spreads over the risk-free benchmark interest rate to model bond pricing (e.g., Subran et al. (2023), BenSlimane et al. (2020), also our ECB colleagues in the market operations). Yields reflect not only bond attractiveness but also the prevailing level of interest rates and the shape of the yield curve associated with different bond maturities. Using a bond spread eliminates differences in bond pricing caused by the dynamics of the risk-free benchmark rate, enabling comparison with the market values of different bonds. The OAS further facilitates comparison with bonds that have embedded options. If a bond has no embedded options, the option-adjusted spread is identical to a bond z-spread, which is approximately the difference between the bond yield and the relevant benchmark risk-free rate.[1]

We use a sample of green and conventional bonds to study whether green bonds systematically trade at lower spreads than conventional bonds. We include a green dummy variable, equal to one if a bond is green, and zero otherwise. To cleanly isolate the effect of this green bond indicator variable on bond spreads, we construct a control group of conventional bonds that are as similar as possible to the sample of green bonds. We obtain this sample of green and conventional bonds by using a k-prototypes matching algorithm, which matches each green bond to exactly one conventional bond from the same issuer and with the most similar characteristics. Starting from the entire universe of all 2295 green bonds issued up to December 2023, we find an appropriate conventional bond match for 457 green bonds. We complement this sample of 894 total bonds (or 457 bond pairs) with daily data on option-adjusted spreads from 2016 to 2023.

On the sample of matched green and non-green bonds, we run three blocks of hypotheses in a bond-date panel setup. In the first block, we explain the OAS of a bond by main factors such as credit risk, liquidity premium, maturity, risk aversion and bond intrinsic characteristics. Then

[1] This measure is more appropriate when comparing bonds with different maturities and trading dates as underlying risk-free rates greatly affect bond prices and yields. If a bond has embedded options, the option-adjusted spread prices in the risks and benefits associated with these options. About 85% of our sample consists of bonds without embedded options and a robustness check that measures the greenium for bonds without options only confirms our results. The OAS is also not affected by liquidity conditions. Differences in yields show the same dynamics and display a bit smaller greenium.

we add a green dummy to the regression to test if being green carries additional information.

In the second block, we focus our attention on the time dimension of the greenium. First, we run an analysis to econometrically confirm the dynamics of the greenium observed in Stylised Figure1. Then, using Securities Holdings Statistics, we identify changes in green bond holders; notably, retail investors acquire a significant share of green bonds - primarily issued by banks - around the trend shift in the greenium. Thus, we investigate the role of higher demand by retail investors in explaining the greenium dynamics.

Next, we study various factors suggested in the literature to further understand the forces behind the greenium dynamics. We explore a mitigating role of rising interest rates on retail investors' preferences, demand for green bonds and greenium in line with the literature posing that retail demand for sustainable investments may be sensitive to negative economic shocks due to higher cost of investments with pro-social preferences (Döttling and Kim (2024), Bansal et al. (2022)). Indeed, investors in green bonds may turn to more conventional assets when liquidity becomes expensive and macroeconomic conditions deteriorate. Following Pastor et al. (2021) and Koziol et al. (2022), we assess if climate concerns and a rise in investors' interest measured by the number of Google searches for the terms "ESG" and "Green bond" are associated with a larger greenium. Finally, we incorporate variables capturing broader macroeconomic and financial performance, such as oil prices, market and volatility indices, as proposed by D'Amico et al. (2023) and Shi and Zhang (2024). These studies suggest that the greenium imperfectly reflects investors' preferences for green assets and is closely correlated with broader economic conditions.

In the third block, we touch upon the large cross-sectional difference in the greenium that can potentially be explained by the lack of a common definition and standard for green bonds[2] and thus differences in credibility and environmental impact of green bonds. Indeed, in the current situation, committed investors need to make additional efforts to identify green bonds with a positive impact on the environment and/or the transition. As documented by multiple studies, investors seek more credible green bonds and are willing to pay a premium to hold a greener green bond (e.g., Sangiorgi and Schopohl (2021), Caramichael and Rapp (2024), Kapraun et al. (2021), Fatica et al. (2021), Flammer (2021)). For this reason, we test if investors prefer green bonds with external review (e.g., certification, second-party opinion) (Yu et al. (2024)), and

[2] The EU Green Bond Standard that aims at providing a gold standard for green bonds in Europe and worldwide enters into force in December 2023 and does not affect our analysis.

if they consider banks committed to environmental programs (Fatica et al. (2021)) as more trustworthy. Sangiorgi and Schopohl (2021) support these assumptions by documenting that unclear and poor reporting on how bond proceeds are allocated to green projects induces a majority of investors to avoid investing in a green bond or to sell a bond if it is already included in the portfolio.

Our analysis provides several findings. First, on the full sample of European green bonds, we find a statistically significant greenium of about -3.7 bps. This result confirms previous findings that, on average, green bonds issued by European entities benefit from investors' trust in the European commitment to climate objectives and thus enjoy a greenium (Kapraun et al. (2021), Caramichael and Rapp (2024)).

Second, we find that the greenium evolves over time. The greenium is mostly non-significant or positive before 2020. Then it widens and becomes more economically and statistically significant in 2020 through early 2022. This finding complements the results of Caramichael and Rapp (2024) who find a significant greenium only from late 2019 and associate it with larger demand pressure from investors in primary markets. Finally, the greenium decreases and becomes insignificant in 2022 through late 2023. The greenium appears to be a non-permanent phenomenon and is not directly related to climate concerns as it was argued back in 2022 when observing the post-COVID market trends in 2020-2021 (Pastor et al. (2021)).

We observe that retail demand for green bonds at least partially drives the greenium of the green bonds in our sample. More specifically, green bonds held by retail investors enjoy a greenium of -6.4 bps, twice as large as the greenium of other green bonds. However, retail demand is sensitive to wider macroeconomic conditions, and the greenium of green bonds primarily held by retail investors decreases with the rise in interest rates. We can tentatively conclude that macroeconomic conditions influence (retail) investors' appetite for green assets, which alters demand pressure and the demand-supply mismatch and thus affects the greenium. D'Amico et al. (2023) confirm the relationship between the greenium, demand-supply imbalances and larger market conditions.

Third, we confirm that credibility significantly influences both bond- and issuer-level dynamics in the relatively trustworthy European green bond market. Green bonds with external reviews exhibit a statistically significant greenium of -4.1 basis points, corroborating findings by Kapraun et al. (2021) and Fatica et al. (2021). However, this result should be interpreted cautiously due to an unbalanced sample of lower-quality green bonds. Similarly, banks adhering to UNEP FI principles command an economically and statistically significant greenium of -5.7 basis points, consistent with Fatica et al. (2021). These findings underscore the market's demand for a robust regulatory framework, such as the EU Green Bond Standard, to ensure the quality and environmental performance of green bonds. Saravade et al. (2025) further supports this need by highlighting the risk of greenwashing in the market as most retail investors prioritize labelled green bonds but show limited sensitivity to their actual environmental impact.

Our paper contributes to the literature in several ways: first, to the ongoing debate on the existence of the greenium in secondary markets; second, and most importantly, we investigate how the greenium evolves over time; third, we uncover the impact of demand by retail investors on the greenium; finally, we examine the role of an issuer's credibility in explaining the presence and magnitude of the greenium. Most papers study the greenium in primary markets. For example, Tang and Zhang (2018) and Flammer (2021) find no greenium in the worldwide corporate green bond sample; Larcker and Watts (2020) document the absence of a greenium in the US municipal bond market; Ehler and Packer (2017), Fatica et al. (2021), observe some greenium, while Caramichael and Rapp (2024) and Kapraun et al. (2021) find an economically significant greenium, up to -20 bps for corporate green bonds.

The cost of funding for companies is defined by bids in primary markets, and thus the greenium in the primary markets are directly related to issuers' financing conditions. Nevertheless, secondary markets play an important role and have a strong effect on primary markets via the price and liquidity of bonds (Bond et al. (2012)). Investors' strong demand for green bonds in the secondary markets can encourage participants in the primary markets to bid more actively because they can easily re-sell green bonds later. Significant oversubscription for green bonds is indeed observed in the primary markets (Caramichael and Rapp (2024)). Thus, a large literature also studies the greenium in secondary markets and finds a wide range of results: Zerbib (2019) finds a "small, albeit significant" greenium of -2bps on a heterogeneous sample of bonds; Karpf and Mandel (2017) find a green bond discount, a positive yield differential for green bonds, of about 8bps, while Ehler and Packer (2017) and Kapraun et al. (2021) document that green bonds perform mostly very similarly to conventional bonds.

Zerbib (2019) and Caramichael and Rapp (2024) investigate the dynamics of the greenium during 2016-2017 and 2014-2021 respectively, thus covering the early stage of the green bond market development and post-COVID green bond market boom. We contribute to the literature by extending the analysis to a period of tight macroeconomic conditions, including the energy crisis, high inflation and tightening monetary policy.

We add to the discussion that retail investors are ready to pay a premium for sustainability investments (Aruga (2025), Saravade et al. (2025)); however, the retail demand for such investments may be affected by economic shocks (Döttling and Kim (2024), Bansal et al. (2022)) thus affecting the greenium.

Our study corroborates on the role of demand-supply imbalances as a driving factor for the greenium by showing the role of increased demand by retail investors on the greenium. Our story is in line with Caramichael and Rapp (2024), who show that higher oversubscription for green bonds in primary markets creates demand pressure and explains the presence of the greenium. D'Amico et al. (2023) go further and propose a term structure estimation of a baseline greenium. The authors argue that such an estimation allows obtaining a greenium that depends purely on environmental concerns and is free from demand pressure or market movements.

All studies agree that credibility is critical for the greenium. The literature investigates various aspects of credibility such as the external review of green bonds (Fatica et al. (2021), Kapraun et al. (2021)), currency and issuer country (Kapraun et al. (2021), Caramichael and Rapp (2024)), issuers' commitment to environmental objectives (Fatica et al. (2021)). Our analysis of green bonds from European issuers confirms prior findings, showing that these issuers, on average, benefit from a greenium, perhaps because of the more stringent transparency requirements that European issuers and financial service providers are subjected to (Caramichael and Rapp (2024)). However, investors continue to distinguish between issuers and bonds based on their credibility. Only green bonds with external review and green bonds issued by UNEP FI signatory banks exhibit a greenium.

The remaining paper is structured as follows. Section 2 discusses the main hypotheses tested in the paper. Section 3 explains the data we use and the matching algorithm to obtain pairs of green and non-green bonds. Section 4 sets up an econometric specification and hypotheses, and discusses the results. Section 5 provides the details of the robustness tests. Finally, Section 6 concludes.

2 Hypothesis development

The European Union has a leading role in sustainable finance with an ambitious policy and regulatory agenda. European governments and the corporate sector are the largest issuers of green bonds and providers of ESG investment funds (CBI (2024)). Due to the European Union's tight climate commitments and multiple regulations regarding sustainable finance (e.g., Sustainable Finance Disclosure Regulation, European Union Green Bonds Principles), European issuers can be considered more credible and tend to benefit from the greenium (Kapraun et al. (2021), Caramichael and Rapp (2024)). At the same time, the overall performance of European green bonds relative to those from other countries may hide any heterogeneity of issuers and time dynamics within the European green bond market. Notably, Figure 1 shows a wide range of differences between the option-adjusted spreads (OAS) of matched green and non-green bonds of the same European issuers as well as varying time dynamics: on aggregate, there is no greenium before mid-2020, a large greenium in 2020-2021, a decreasing greenium from end-2021 and almost no greenium in 2023. This observation suggests that investors differentiate even across green bonds of potentially the most credible green bond market. What factors explain this heterogeneity? What macroeconomic factors do they follow?

[PLACE FIGURE 1 HERE]

In this section, we develop hypotheses that could explain the driving forces behind the observed cross-sectional and time dynamics of the greenium. We proceed step by step, in establishing various relationships starting from a simple observation of whether a greenium exists for an average European green bond. Then we dive deeper, to understand the time dynamics of the greenium. Finally, we discuss if investors are sensitive to the credibility of issuers and bonds in a market which can already be considered more credible.

An extensive literature on green bonds has been in search of the greenium, a phenomenon traditionally linked to investors' preferences. Green bonds can be seen as an instrument to identify the effect of non-pecuniary motives - specific pro-environmental preferences - of investors (Zerbib (2019)). Using green bonds, we can assess if investors are ready to pay a price - accept a lower return - for holding green bonds. The evidence for secondary markets is still largely mixed: Tang and Zhang (2018) and Flammer (2021) find no evidence for corporate green bonds. Employing comprehensive data on globally issued green bonds Kapraun et al. (2021) refines previous findings by suggesting that green bonds denominated in EUR and issued by governmental and supranational entities benefit from a greenium due to the higher credibility of projects they finance, while corporate green bonds enjoy a greenium only when certified or issued by larger corporations.

On the other hand, studies focusing on primary markets tend to find a more consistent evidence of a statistically significant greenium across different samples (Ehler and Packer (2017), Fatica et al. (2021), Baker et al. (2018)). The exceptions are Zerbib (2019), Larcker and Watts (2020) who find little or no greenium for municipal green bonds. Caramichael and Rapp (2024) refine previous analysis and suggest that a significant greenium emerges only from 2019 onwards, coinciding with the growth of the sustainable asset management industry following EU regulation, thus hinting at the evolution of the greenium over time. The authors conclude that at issuance, on average, the greenium is primarily allocated to local euro issuers, while in the non-euro area market there appears to be no significant average greenium.

Our first hypothesis thus consists of testing whether there is an average greenium in the European corporate green bond secondary market over the full period 2016-2023; whether investors - as expected - lend significant credibility to European issuers based on the EU's strong policy stance on sustainable finance.

Hypothesis 1: Green bonds of European issuers trade at a greenium on the full sample over the period 2016-2023.

The next three hypotheses explore the time dimension and drivers behind the greenium dynamics. Stylised Figure1, as well as recent studies, find varying performance of green assets over time: Pastor et al. (2021) and Van der Beck (2021) show that green and ESG equities outperformed their traditional peers in recent years, particularly following the COVID-19 outbreak; Caramichael and Rapp (2024) document a statistically significant greenium only after 2019; IFC and Amundi (2024) suggest that green bond markets, along with other ESG investments, have been affected by the recent period of high inflation and tightening monetary policy worldwide.

In this hypothesis, we thus test statistically the time trend observed in Stylised Figure 1 to see if we can confirm econometrically the time-varying nature of the greenium.

Hypothesis 2: In the euro area's secondary bond market, the greenium varies over time, being economically and statistically significantly negative in some periods but not others.

The main driver behind the greenium is assumed to be investors' preference for green bonds and, specifically, a demand-supply mismatch, as there are potentially more investors interested in acquiring green bonds relative to the market supply (Zerbib (2019), Caramichael and Rapp (2024)). In particular, Caramichael and Rapp (2024) measure demand by oversubscription and green bond index inclusion and relate the emergence of a statistically significant greenium in primary markets to increased demand for green bonds by corporate bond investors following the European Union's broad sustainable finance policies in 2019.

Although institutional investors drive this market, there is an interest and effort to expand access to green bonds to retail investors (Climate Bond Initiative (2018a)) as well as growing evidence of retail investor participation (Azad et al. (2024)). Institutional investors - the object of most studies on the greenium - tend to value the green label and particularly with stronger credibility and better environmental performance (e.g., Fatica et al. (2021), Sangiorgi and Schopohl (2021)); however, we know little about individual investors' preferences for green bonds.

A growing literature on retail investors investing in pension and investment funds suggests that individual investors do have strong sustainability preferences and ready to forgo some financial return (Riedl and Smeets (2017), Bauer et al. (2021), Andersen et al. (2023)). In the literature on green bonds, Saravade et al. (2025) demonstrate a "green label effect" in a choice experiment, whereby most retail investors favour labelled green bonds over non-green alternatives, even when the latter offer higher returns, thus showing limited sensitivity to the bonds' actual environmental performance. Only a small subset of investors prioritizes enhanced environmental impact and reporting quality despite lower returns. Similarly, Aruga (2025) finds, based on a survey of Japanese respondents, that retail investors generally favour green bonds with annual interest rates above a certain threshold. However, those with greater altruism, environmental awareness, access to green bond information, or frequent investment activity exhibit a stronger preference for green bonds.

The absence of data hinders efforts to determine whether retail investors genuinely prefer green bonds and accept lower returns in practice, as opposed to merely indicating such preferences in academic surveys or experiments. This study leverages a unique opportunity by utilizing the ECB's proprietary securities holdings statistics to evaluate retail investors' actual preferences for green bonds. Analysis of these data reveals a sharp increase in retail holdings of green bonds — predominantly those issued by banks — in 2020, coinciding with a trend shift in the greenium. This surge in interest may stem from heightened beliefs about climate change and environmental risks triggered by the COVID-19 pandemic, consistent with findings by Choi et al. (2020), who show that retail investors, unlike institutional investors, tend to divest from carbon-intensive firms after experiencing unusually warm local temperatures. We thus test the hypothesis that higher retail investor demand drives the increase in the observed greenium.

Hypothesis 3: The greenium dynamics in the euro area secondary bond market is driven in *part by retail investor demand.*

To further understand the dynamics of the greenium, we explore factors potentially affecting retail investors' environmental preferences. The literature on green bonds identifies various influences on the greenium. Given that retail investors hold a significant portion of the bonds in our sample, studies examining their behaviour may provide valuable insights. One key factor in 2022–2023 is shifting macroeconomic conditions. Research suggests that retail investors' pursuit of pro-social investment preferences (Riedl and Smeets (2017), Bauer et al. (2021)) can be costly, particularly during negative economic shocks. With limited capital and a tendency to actively reallocate investments across funds (e.g., Ben-Rephael et al. (2012), Ceccarelli et al. (2024)), retail demand for sustainable investments may be sensitive to income shocks or availability of alternative opportunities (Döttling and Kim (2024), Bansal et al. (2022), Koijen and Yogo (2019)). Consequently, retail investors may shift from green bonds to conventional assets when liquidity becomes costly and macroeconomic conditions worsen, especially with rising interest rates.

Other studies highlight retail investors' sensitivity to climate concerns, ESG news, and personal experiences with climate change (Choi et al. (2020), Li et al. (2024)). Notably, Pastor et al. (2021) argue that climate concerns drive the greenium in both equity and green bond markets, with heightened effects during the COVID-19 pandemic. Koziol et al. (2022) link a larger greenium to increased investor interest in green bonds and ESG investments, measured through Google searches for related terms.

An emerging strand of literature suggests that the greenium imperfectly reflects investors' preferences for green assets and is influenced by broader macroeconomic and financial variables, such as oil prices and market indices (D'Amico et al. (2023), Shi and Zhang (2024)). Shi and Zhang (2024) estimate that 20–50% of the greenium in bonds and equities is explained by rising oil prices, which increase costs, reduce profits, and elevate default risks for fossil-fuel-reliant firms. Although our study focuses on green and conventional bonds from the same issuer, mitigating this effect, oil prices may still indirectly influence demand for green bonds and, thus, the greenium.

As the relationship between macroeconomic factors and the greenium remains unclear, we test several variables potentially linked to investors' preferences and demand for green bonds, as suggested by the literature. Specifically, we examine whether investors are sensitive to rising short-term interest rates and whether the greenium correlates with oil futures, market prices

(MSCI index), market volatility (VIX index), and investor attention to ESG and green bonds (measured via Google searches for relevant terms).

Hypothesis 4: The greenium dynamics in the euro area secondary bond market is influenced by the macroeconomic environment.

The next two hypotheses investigate the role of bond and bank credibility previously identified in the literature in explaining the greenium of European "credible" green bonds. A simple observation of the dispersion in the greenium among matched pairs of European green bonds (Stylised Figure 1) shows that investors differentiate even among European green bonds. If the greenium is driven by investors' environmental preferences, then investors should be particularly concerned about the credibility of the green projects they finance. Indeed, a survey of European asset managers suggests that strong green credentials, both pre- and post-issuance, are among the most frequently named factors impacting respondents' decisions to invest in a green bond (Sangiorgi and Schopohl (2021)). The authors further state that "unclear and poor reporting on how bond proceeds are allocated to green projects induces a majority of investors to not invest in a green bond or to sell a bond if already included in the portfolio". These observations indicate that the credibility of a green bond serves as a basis for differentiation in a market lacking common regulation, standards and enforcing mechanisms to ensure positive environmental impact of green bonds. This is also confirmed by empirical studies showing that only certified green bonds trade at a statistically significant greenium (Kapraun et al. (2021), Fatica et al. (2021)).

We thus test if in our sample of relatively credible green bonds (as issued by European companies with stronger sustainability regulation), effectively only green bonds with external review, trade at a greenium. Indeed, external review - whether in the form of a second-party opinion, verification or certification - is optional under the most widely used ICMA Green Bond Principles. It is also costly and time-consuming for the issuer, but if an issuer chooses to obtain external review for its green bonds, this may signal a stronger commitment to investors.

Hypothesis 5: Only green bonds with external review trade at a greenium.

Banks are major issuers of green bonds in the market and in our sample. Although banks do not directly produce emissions, they play a key role in determining which companies and industries receive financing, thus indirectly (Scope 3 emissions) contributing to the overall carbon footprint. The literature suggests that a way to assess banks' credibility in issuing green bonds is to look at their public commitments. We follow Fatica et al. (2021) and Delis et al. (2021) who choose adherence to the United Nations Environment Program Finance initiative (UNEP FI), a partnership established between the United Nations Environment Program and the financial sector, as a signal of banks' environmental commitments. This partnership seeks to encourage financial institutions to better implement sustainability principles at all levels of operations. Banks that sign the UNEP FI partnership publicly commit to including sustainability principles in their operations and investments.

Caramichael and Rapp (2024) find that banks benefit from a greenium while Fatica et al. (2021) argue that only banks that are signatories to the UNEP FI enjoy greenium. We test if indeed only bonds issued by banks with better green credentials in our sample trade at a greenium.

Hypothesis 6: Only green bonds issued by banks that are UNEP FI signatories trade at a greenium.

3 Data

3.1 Identifying green bonds

Green bonds are similar to conventional bonds except that their proceeds are earmarked to exclusively finance projects with environmental benefits. Up until early 2024, there was no global or even regional regulatory standard to define "environmentally beneficial" projects, and market participants relied on voluntary market principles.[3]

Currently, a widely used classification framework are the International Capital Market Association (ICMA)'s Green Bond Principles. The framework establishes four main criteria for voluntary best practices by which bonds are classified as green bonds. First, a bond is considered green if the *Use of Proceeds* principle is satisfied. According to ICMA, this is the case if the bond issuer earmarks the bond proceeds to finance eligible green projects[4] that are described in their legal documentation. Second, the *Process for Project Evaluation and Selection* principle is satisfied if the issuer clearly communicates what the objectives of the green project are, what

[3] In December 2023, the European Green Bond Standard (EU GBS) Regulation entered into force. The EU GBS aims to provide a gold standard for green bonds with a unified approach to classification, pre-, post-, and annual reporting of the use of proceeds, as well as placing external review providers under ESMA's direct supervision. While the label is voluntary, the requirements can provide a benchmark for a green bond for market participants. Nevertheless, this does not affect our analysis, as our sample ends before the Regulation came into force.

[4] These projects fall under the categories of renewable energy, energy efficiency, pollution prevention and control, environmentally sustainable management of living natural resources and land use.

makes the project eligible, and what the associated environmental and social risks are. The third principle refers to the *Management of Proceeds* and requires the bond proceeds to be clearly managed and tracked within the company's financial structure, by creating a sub-account for the proceeds. Finally, the *Reporting* principle is fulfilled if companies publish a report with details regarding green bond use-of-proceeds and financed projects. To further assure the integrity of green bonds, such principles recommend but do not require an external verification of the use of proceeds. Multiple market participants provide solutions such as an external review, second-party opinion or green label certification; however, the process lacks standardisation across methodologies and reporting.

As of November 2023, the share of euro area green bonds aligned with ICMA principles amounted to a total notional outstanding value of around EUR 900 billion. Bonds fulfilling all four ICMA principles and having third-party review made up 99% of that amount (see Figure 2). In other words, the vast majority of green bonds are of the highest quality of greenness according to the standard.

[PLACE FIGURE 2 HERE]

For this study, we use Bloomberg as a data provider since it identifies green bonds that are in alignment with the ICMA principles and indicates whether each of the four ICMA GBP principles is satisfied. Bloomberg identifies whether ICMA principles are fulfilled based on the sustainability framework and statements in the at-issuance documentation of a bond, such as bond term sheets, prospectuses, and offering circulars. To classify a bond as green, Bloomberg analysts ensure that all language used in the document states that 100 percent of the net proceeds or an amount equal to the net proceeds is used for eligible green projects, i.e., meeting the use-of-proceeds criterion. Likewise, other ICMA principles are identified based on the at-issuance documentation of a bond if there is a reference to the *Process for Project Evaluation and Selection*, the *Management of Proceeds*, and the *Reporting* principle. In addition, there is a variable that provides information on whether a green bond is certified as green by a third-party assurance provider. These Bloomberg indicators allow for the classification of green bonds into three different levels of greenness: the lowest level of greenness applies when bonds fulfil the use-of-proceeds principle, but not all other principles. Bonds that respect all four ICMA principles are considered to be at the second highest level of greenness. Finally, bonds with the highest greenness satisfy all ICMA principles and have also received the review of a third party. These bonds may be considered to be at lower risk of greenwashing.

3.2 Matching

The aim of this analysis is to understand whether green bonds are priced differently from conventional bonds by the market, purely based on their "green" character. Issuers of green bonds and those of conventional bonds may differ, thus it is essential to eliminate issuer-based impacts on pricing from our analysis. For example, firms that issue green bonds may be more aware of climate-related risks, may have lower emissions and may be overall better prepared for climate shocks (Flammer (2021)). As climate risks are not fully reflected in conventional risk metrics, such as the probability of default or credit rating (Carbone et al. (2021)), issuer differences could result in unobserved characteristics that are correlated with the issuance of green bonds, which might have an unobserved impact on the pricing of green bonds. For this reason, it is essential to separate the impact of the green bond dummy from the impact of the green bond issuer.

We achieve this by restricting our sample to include only green and conventional bonds that have been issued by the same green bond issuers. Additionally, bond prices are also determined by bond-level characteristics, such as the maturity, duration, seniority, or coupon type of a bond. We address this by minimising these differences in our sample selection through a matching algorithm. The remainder of the section describes this matching procedure in greater detail.

As a first step in obtaining our sample, we downloaded from Bloomberg the entire universe of green bonds issued in the euro area as of the end of December 2023. We used Bloomberg's green bond flag to identify green bonds satisfying ICMA's first principle on the *Use of Proceeds*. As of December, the universe of all green bonds consisted of 2,295 active and matured bonds.

In the second step, we compiled a list of all the bond issuers from this universe of green bonds. This list of green bond issuers provided the basis for our universe of potential conventional bond matches, as we used it to identify all conventional bonds listed in the ECB's internal Centralised Securities Database (CSDB).

In the third step, we cleaned this universe of conventional bonds. Since not all data providers use the same methodology to classify green bonds, there can be discrepancies in the universe of green bonds. To avoid including in our sample of conventional bonds any bonds classified as green by other data providers, we removed from the conventional bond universe any bonds that were not classified as green by Bloomberg but had a green indicator in Dealogic. From this, we obtained a list of more than 266,000 bonds that had been issued by the previously identified issuers of green bonds.

On this subset, we applied a k-prototypes matching algorithm (Huang (1997), Huang (1998)) to match the most similar conventional bonds to our set of green bonds by minimising the following dissimilarity function:

$$d(GC) = \sum_{i=1}^{n} \omega_i (g_i - c_i)^2 + \sum_{j=n+1}^{m} \omega_j \delta(g_j c_j) \tag{1}$$

where Matrix G is a set of green bonds consisting of n normalised numerical variable vectors g_i and m categorical variable vectors g_j and C is a matrix of conventional bonds consisting of n normalised numerical variable vectors c_i and m categorical variable vectors c_j. $\delta(g, c)$ is a dissimilarity function that takes the value 1 for each pair of categorical variables that are not alike and 0 if the pair of categorical variables is the same. The weights ω_i and ω_j can be chosen to represent the order of importance of each individual matching variable. First, we restrict the sample to only include bond pairs for which the issuer and the calendar year of maturity was the same. To perform the matching algorithm, we define the vectors g_i and c_i as consisting of the numerical variables nominal amount issued and duration. These variables are pre-processed and normalised by scaling them to unit norm and enter the dissimilarity function with the weights 1 and 20, respectively. The vectors g_j and c_j consist of the variables bond seniority, currency, debt type and issue date. For a given bond pair, the output vector is assigned 0, if the variable takes the same value for both bonds and 1 otherwise. The result is then multiplied by the weights 100 for bond seniority and currency, by 5 for the debt type and by 0.5 for the issue date.[5]

This k-prototypes matching algorithm allows us to identify exactly one conventional bond for each green bond in our sample that was the most similar one according to the matching variables, was issued by the same issuer and has the same maturity year. After implementing all these steps, we obtained a sample of 447 euro area bond pairs, i.e. 894 individual bonds from 79 unique issuers.

[5] Consider, e.g., a green bond with a normalised amount issued of 0.5, a normalised duration of 0.1, of senior unsecured seniority, issued in EUR and as a zero coupon bond on 01/01/2019 and a conventional bond with a normalised amount issued of 0.3, a normalised duration of 0.1, of senior unsecured seniority, issued in USD as an index-linked bond on 01/01/2017. For this bond pair, the dissimilarity function would take $\delta = 1(0.5 - 0.3)^2 + 20(0.1 - 0.1)^2 + 100(0) + 100(1) + 5(1) + 0.5(1)$

3.3 Representativeness

To assess the representativeness of our sample, we compare the green bonds that remain in our sample after applying the matching algorithm, with the list of all green bonds initially extracted from Bloomberg. Figure 3 compares statistics for the sample of green bonds used in this study and those of the entire universe of euro area green bonds in Bloomberg. Overall, our sample is very similar to the entire euro area green bond market.

First, around 70% of green bonds in our sample and the full sample are issued in EUR. Second, green bonds with external review make up the vast majority of green bonds in the euro area in both samples, with a slightly larger share of green bonds with external review in our sample, i.e., 98% of our sample vs. 96.5% of all euro area green bonds issued up to December 2023. Third, our sample appears very representative of the entire market when assessing the interquartile range and median issue size.

The largest difference between our sample and all euro area green bonds is visible in the issuer country, as our sample has a significantly larger share of bonds issued by German issuers, while bonds issued by French issuers are under-represented.

In terms of the issuer sector, our sample is broadly in line with the whole green bond market, although Financials and the public sector make up a slightly larger share than in the entire green bonds market.

This comparison suggests that our study is able to characterise the developments of the overall euro area green bond market. Furthermore, we address the robustness of our results with respect to the issuer country in a regression that excludes German issuers (see Table 10).

[PLACE FIGURE 3 HERE]

3.4 Market data and descriptive statistics

The term *greenium* describes the idea that investors are willing to pay a premium to hold a green bond rather than a conventional bond, as they are willing to accept lower monetary returns in exchange for supporting environmentally beneficial activities. If this is the case, it should be reflected in better funding conditions for green bond issuers, thus resulting in lower yields for green bonds. However, one important component of the yield of a bond is the underlying risk-free rate, which is dependent on the slope of the yield curve and the current level of interest rates.

Comparing bonds with different maturities and issued at different points in time is therefore better done using a spread measure, which only looks at the relative pricing of the bond, and not at the risk-free rate. To additionally account for any embedded options (e.g., a bond may be callable or puttable), we use the option-adjusted spread (OAS), which is commonly used among professionals (e.g., Subran et al. (2023), BenSlimane et al. (2020)). About 85% of our sample consists of bonds that do not have any embedded options.[6] In the absence of embedded options, the OAS is equivalent to the bond z-spread, which is a constant discount spread over the benchmark yield curve. This measure is more appropriate when comparing bonds with different maturities and trading dates, as underlying risk-free rates greatly affect bond prices and yields.

For our analysis, we use daily data on the OAS from Bloomberg for our sample of 894 green and conventional bonds between 1 January 2016 and 31 December 2023. Additionally, we use bid and ask prices, and the probability of default, as well as the following macro variables: 3-month euro area benchmark yield, the 10-year German government bond yield and the VIX index. For our final sample, we only keep observations for which all variables are populated for both bonds in a pair. Accordingly, a bond pair is recorded in our sample whenever both bonds are traded on a given day, and pricing data are available. Once both bonds of a pair have been issued and are traded on the secondary market, they enter the sample and exit when either bond in the pair matures.

Table 1 shows the summary statistics of the green and conventional bonds in our sample, as well as t-tests on the differences between the groups. For static variables, we test the differences using the cross-sectional sample, and for dynamic variables, such as the OAS, the bid-ask spread, and duration, we use the panel data set. As can be seen from the first five rows, the static variables show no significant difference, as accounted for by the matching algorithm. However, dynamic variables, such as duration and the bid-ask spread, show statistically significant differences. We do not restrict our matching further, but instead include these variables in the regressions and run additional robustness tests, which can be found in Table 9, to confirm the robustness of our results.

Table 1 also shows the results of a t-test on the straight difference in OAS between green and conventional bonds, which is statistically significant, with an average of 3.9 bps. While this provides tentative initial evidence for the presence of the greenium, this hypothesis is tested

[6] We run a robustness check that measures the greenium for bonds without options, and this specification confirms our results.

through more rigorous analyses in the next section.

[PLACE TABLE 1 HERE]

4 Results

4.1 Econometric specification

To investigate if there is a price differential between green and conventional bonds, we first introduce a preliminary step in our analysis by running a regression that explains the price of a bond by standard factors. In our analysis, we use option-adjusted spreads (OAS). We retain five categories established in the literature that explain the formation of the bond return: (i) a risk-free rate, duration, and time to maturity; (ii) credit risk; (iii) risk aversion; (iv) liquidity premium; and (v) intrinsic characteristics of bonds, such as maturity type or pay-off seniority.

First, risk-free rates are key factors in bond pricing. We include risk-free interest rates of long and short maturity to account for the term structure of bonds: the 3-month Euribor and the German 10-year sovereign bond rate. We also include duration in the regression to capture the interest rate risk of a bond.

Second, a key variable defining bond yields is credit risk. We use the issuer's probability of default calculated by Bloomberg as a proxy for credit risk.

Third, an important factor affecting bond yields is the market liquidity of bonds (Longstaff et al. (2005), Han and Zhou (2016), Bao et al. (2011)). We use the bid-ask spread as a measure of market illiquidity.

Fourth, even if probabilities of default and recovery rates are constant, the risk premium may still vary due to a change in risk aversion. For example, during financial stress, all bond spreads tend to rise independently of bond ratings. The increase in the implied volatility in the global stock markets, represented by the Vstoxx or the VIX, is used as a measure of financial stress and risk aversion (see, for example, Coudert et al. (2011) and Rey (2016)).

Finally, we add a dummy variable to indicate whether a bond is eligible for the ECB Asset Purchase Program or Eurosystem Collateral framework. As being eligible for Eurosystem monetary policy operations reduces bond spreads (Coudert and Salakhova (2020); Abidi and Miquel-Flores (2018); De Santis et al. (2018)), market participants may value ECB/Eurosystem-eligible bonds independently of other characteristics. We also take into account the intrinsic features of bonds by adding coupon-type, issuer, currency, debt-type and seniority fixed effects. As we are interested in estimating the average difference in spreads between green and conventional bonds, we cannot use bond fixed effects in this regression as these would absorb the difference in spread levels we are trying to measure. Instead, we use the above control variables to model any observable differences that would lead to a difference in spreads that cannot be attributed to the green bond dummy variables. This results in the following econometric specification:

$$OAS_{it} = \alpha_i + \beta Green_i + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{2}$$

In this panel setup, we observe each bond (i) at time (t). We regress the outcome variable, i.e., the (OAS_{it}), on a set of dummy variables, (α_i), i.e., issuer, year, debt type, currency, coupon type, and seniority fixed effects, as well as whether the bond has any embedded options.[7] (X_{it}) is a set of time-varying controls such as the bid-ask spread, and probability of default.[8] Other controls include the log of the amount issued, bond eligibility as ECB collateral, duration, and residual maturity. (M_t) are macro variables: the 3M Euribor interest rate, the 10Y German Bund yield, and the VIX Index. All control and macro variables are of daily frequency, except for the issuer's estimated probability of default, which varies, depending on the input data, between daily and quarterly frequency. Finally, we add a green bond dummy variable equal to 1 if a bond is green and 0 if a bond is conventional. As observations of the same bond and of the same issuer are likely correlated, we cluster standard errors at the bond and issuer level to account for serial and cross-sectional correlation.

Under the assumption of unbiasedness, the estimator $\hat{\beta}$ can be interpreted as the effect of a bond being green on the bond spread, i.e., $\hat{\beta}$ can be interpreted as the greenium.

[7] As for the other control variables, option fixed effects are added to account for differences in matching between bond pairs. Although the OAS adjusts the spread for embedded options to get a spread estimate that takes into account the probability of different outcomes, other factors can play a role. For example, investor preferences might still affect whether investors would buy a bond with embedded options at all.

[8] We use Bloomberg's issuer 1-year default probability. This probability is modeled by Bloomberg's DRSK model (see Bondioli et al. (2021) and Bondioli et al. (2021)), which is a hybrid approach between a statistical default model (in line with Altman (1968)) and a structural distance-to-default model that uses market pricing (based on Duffie et al. (2007)). The model can be applied to both public and private firms, as market pricing for private firms is substituted by public firm data of the same sector and region. This allows us to include the variable in our entire sample.

4.2 Greenium: baseline regression

As we would like to explore whether there are differences in the pricing of green and conventional bonds, we start our analysis with the simplest question: Do green bonds exhibit a greenium, i.e., do they trade at systematically tighter spreads than conventional bonds? In other words, we test the following hypothesis:

Hypothesis 1: Green bonds of European issuers trade at a greenium on the full sample over the period 2016-2023.

To do so, we first explain a bond OAS with conventional metrics, excluding the green dummy, in the baseline regression specified in Equation 2. In the next step, we add the green bond dummy to the regression to see whether being green has any additional explanatory value. The results of these regressions can be found in Table 2.

[PLACE TABLE 2 HERE]

Comparing the effects of the conventional risk metrics between the two regressions, we first analyse the standard factors explaining bond yields. The positive and significant coefficient on the 10-year German Bund yield suggests that the higher the overall remuneration on bonds, the larger the overall level of spreads. This is in line with the argument that spreads rise with the level of the yield curve, as investors require greater incentives to seek additional remuneration through credit risk. By contrast, when controlling for long-term yields, the correlation with short-term yields is negative. This may be because higher short-term yields signal incipient monetary policy tightening in response to rising inflation and economic strength. In periods of economic expansion, defaults tend to be low, and credit risk falls, leading to a tightening in spreads.

Higher uncertainty in markets, indicated by a higher value of the VIX Index, shows a statistically significant correlation with higher bond spreads. The probability of default is positively correlated with the OAS, accounting for larger credit spreads, while market liquidity, modelled by higher values of the bid-ask spread does not show any statistically significant effect.[9] Next, if a bond is eligible for use as ECB collateral, which indicates lower risk, it exhibits statistically significantly lower spreads by about 20 bps. Larger bond amounts issued are associated with

[9]This is partly due to issuer-fixed effects which absorb some of the differences in bid-ask spreads.

lower spreads, that is an increase in the amount issued by 1 percent corresponds to a 2.5-2.8 bps decrease in spreads. A one percentage point higher coupon rate or duration are both linked to an about 3 bps higher spread.

Including the green bond dummy in the regression shows that all green bonds in our sample over 2016 and 2023, on average, exhibit lower spreads of about -3.7 bps, with the highest statistical significance. As we performed the matching of our sample, any bias of the greenium estimate, $\hat{\beta}$ should be minimal under the unconfoundedness assumption that matching on observable characteristics also captures potential differences in unobservable characteristics. This means that if the matching was perfect, we could expect that, on average, green and non-green bonds exhibit the same characteristics and, thus, the green bond dummy would be uncorrelated with the control variables. Indeed, comparing the results from both regressions, we find that the coefficients on conventional risk metrics are very similar regardless of whether the green bond dummy is included or not. This supports the argument that the $\hat{\beta}$ coefficient of the green dummy variable can be interpreted as the causal effect of the greenness of a bond on its pricing. Moreover, it provides more confidence in the matching as it shows that the correlation between the green bond dummy and the control variables is minimal. However, to account for imperfections in the matching and to err on the side of caution, we include the set of control variables in all of the following specifications.

4.3 Dynamics of the greenium over time

As shown in Figure 1, there is a large heterogeneity in the difference in spreads between green and conventional bonds, both in the cross-section and over time. In particular, towards the end of 2019, the median difference in spreads turns negative, and by the second quarter of 2020, the dispersion widens, and the 25th percentile drops significantly. The median difference in OAS between green and conventional bonds, i.e., the median greenium, keeps increasing until the end of 2021 but becomes smaller subsequently and largely disappears in the second half of 2023. This observation suggests that the greenium changes over time. This motivates the next hypothesis:

Hypothesis 2: In the euro area's secondary bond market, the greenium varies over time, being economically and statistically significantly negative in some periods but not others.

To confirm whether the time trend observable in stylised Figure 1 holds when testing it statistically, we revisit the baseline Regression 2. This time, we interact the green bond dummy variable with quarterly fixed effects:

$$OAS_{it} = \alpha_i + \beta Green_i + \xi quarter_t + \tau \mathbf{quarter_t} \times \mathbf{Green_i} + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{3}$$

A significant coefficient (τ) on the interaction term between the green dummy variable and the quarterly fixed effect would indicate changes to the greenium across time. Indeed, as indicated in Table 3, the greenium only starts to appear towards the end of 2019, as the interaction term is significant and positive in the period between Q3 2017 and Q2 2019. The greenium dummy is estimated at –9 bps with significance at the 10% level. The combined effect from both coefficients is depicted in Figure 4 and shows that during the period from Q3 2017 to Q2 2019, the greenium did not exist and only turned negative thereafter. While the quarterly interaction terms are also insignificant before 2017, the interpretation of the greenium should be more cautious given the very small sample size. Until Q2 2017, our sample includes only up to 13 green bonds in any given quarter.

[PLACE TABLE 3 HERE]

To get more clarity on the combined effect and the size and significance of the greenium, we repeat the baseline Regression 2, including the green bond dummy variable. However, this time, instead of using the entire sample across all periods, we divide the sample into quarterly sub-samples. We then run the baseline regression on each of the sub-samples to measure the greenium for each quarter of our time series and store the coefficient, ($\hat{\beta}$), on the green bond dummy variable. We then plot the quarterly greenium, i.e., ($\hat{\beta}$) estimates, as well as the corresponding 95 percent confidence intervals. The result of these regressions is shown in Figure 5. Again, we see that the estimated average coefficient starts to drop towards the end of 2019 and then increases in magnitude, becoming significant in the second half of 2020. It remains at the level of about –5 bps until approximately the end of 2022, when it starts progressively to decrease in magnitude. Finally, it turns insignificant at the end of 2023.

[PLACE FIGURES 4 AND 5 HERE]

What explains this change in the greenium over time? One possible driver may be a change in the demand for green bonds. As climate concerns rise, green bonds may attract more attention from investors who want to contribute to climate-benefiting projects. Despite the exponential growth of the green bond market, as shown previously in Figure 2, it still represents only about 4% of the entire euro area bond market. If demand is very high and exceeds supply, it may put pressure on the market and drive prices up. Caramichael and Rapp (2024) find a similar shift in the greenium trend in the primary markets in 2019. They relate the emergence of the statistically significant greenium in primary markets to increased demand for green bonds by corporate bond investors following the European Union's broad sustainable finance policies in 2019. In the next hypothesis, we investigate whether the demand for green bonds has changed over time and whether it could explain the dynamics of the greenium.

4.4 The greenium and investor demand

We complement our dataset of daily bond spreads with data from the Securities Holdings Statistics by Sector (SHSS) database. The SHSS keeps track of quarterly bond holdings of all sectors within each euro area country. Using the unique ISIN of each bond as an identifier, we are able to match quarterly holdings with the daily data on our bonds. This allows us to complement our bond data with information on how much of each bond in our sample is held by different types of euro area investors in a given quarter.[10] When it comes to measuring demand, the difficult part is that the total demand observed, such as, e.g., the total amount purchased, is highly endogenous to the amount issued. As investors will simply absorb the supply that was issued, total holdings are not an ideal statistic to look at when estimating demand pressure. Rather than focusing on total holdings, we thus look at relative holdings. In particular, we examine whether some investors increased their relative share of green bond holdings over time. If a particular investor has a strong preference for green bonds and is willing to pay a premium for them, this can increase the price if that investor holds a sufficiently large portion of the respective bond. Therefore, we compute the share of ownership of each sector for each bond by dividing the holdings of investor sector (s) of bond (i) by the total amount outstanding of bond (i) for each quarter.

[10]Since the database only covers euro area holders, any bond holdings outside of the euro area cannot be tracked. The total holdings, therefore, do not necessarily sum up to the full outstanding amount of a particular bond. For our sample, the database captures, on average, around 70% of all holdings, with an interquartile range from 48% to 100%.

[PLACE FIGURES 6 AND 7 HERE]

Figure 6 displays the average holding share of euro area investor sectors across all bonds in the sample for each quarter from 2016 to 2023. Euro area holdings statistics are based on ECB (Securities Holdings Statistics by Sector) data and available for 800 of the 894 bonds in our sample[11]. Initially, investment funds (IFs), insurance companies, and pension funds (ICPFs), and to a lesser extent, banks, held, on average, the largest shares of a given bond in our sample. However, the investor composition changed dramatically over time. In particular, the share of retail investors (households and non-financial corporations) started to increase from the end of 2019 and reached the largest share of all sectors in the second quarter of 2020, while the share of euro area institutional investors fell. This development also mirrors the dynamics in the greenium over time that we observed earlier, and the large increase in the share of retail investors in 2020 coincides with the time period during which the greenium turned significant.

We further investigate the finding by comparing the patterns of the share of retail investors for all conventional bonds and green bonds in our sample, as well as for the full list of green bonds issued that we obtained from Bloomberg before applying the matching algorithm. Figure 7 shows the average retail holding share across all green and conventional bonds in our sample and for all green bonds in the euro area. The marked increase starting from the end of 2019 is visible across all bonds. Moreover, we find that this increase in the share of retail investors is largely aligned between both the green and conventional bonds in our sample. These closely matched dynamics make it easier to measure differences in spreads between two bonds within a pair and trace them back to green preferences, rather than to other differences between these bonds. Moreover, compared to the full list of green bonds issued, our sample appears relatively representative, as it features dynamics quite similar to those of the unrestricted list of euro area green bonds.

Overall, these observations suggest that retail investors may play a role in driving the greenium which we test in the next hypothesis:

Hypothesis 3: The greenium dynamics in the euro area secondary bond market is driven in part by retail investor demand.

[11]These holding shares are computed by taking the amount held by each sector of a given bond and dividing it by the total outstanding amount of the respective bond. Then, the simple average of these shares is taken across all green bonds in the sample at a given point in time. As pricing data, such as the OAS, are not weighted by the size of the bond in the sample, the numbers on holding shares are also not weighted by the size of the bond but represent simple averages.

To confirm these findings statistically, we define a "retail share" variable as the holdings of retail investors of bond (i) at time (t), divided by the total amount outstanding of bond (i) at time (t). Moreover, we add another control variable, "EA share," which is the share of other euro area investors of bond (i) at time (t), calculated as the sum of all other sectors' holdings of bond (i) at time (t), divided by the total amount outstanding of bond (i) at time (t). We add these two variables to the baseline regression, as well as the interaction of the retail share with the green bond dummy variable. Given the structure of the holdings data, we also cluster standard errors by quarter. This gives us the following regression:

$$OAS_{it} = \alpha_i + \beta Green_i + \iota RetailShare_{it} + \lambda \mathbf{RetailShare_{it}} \times \mathbf{Green_i} + \kappa EAshare_{it} + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{4}$$

In this regression, the estimator $\hat{\lambda}$ can be interpreted as the difference in spreads that a green bond exhibits when retail investors change their holding share of this green bond from 0 to 100 percent. In other words, and under the exogeneity assumption, it measures the premium that retail investors are willing to pay for a green bond relative to other investors. The results from this regression are summarised in Table 4.

[PLACE TABLE 4 HERE]

Indeed, we are able to confirm the correlations we have seen in the descriptive statistics. If retail investors increase their bond holdings from 0% to 100%, the green bond trades, on average, at about -3.17 bps lower than its conventional match. Taken together, the coefficient β and the interaction term λ shows that retail investors forgo part of their profits, -6.4 bps, when buying a green bond instead of a conventional one. This greenium associated with retail investors is larger than the baseline greenium of -3.7 bps. The larger spread differential suggests that retail investors have a particular preference for green bonds and drive part of the greenium.

However, the result does not imply that green bonds become overall more expensive when retail investors buy them. The coefficient $\hat{\kappa}$ measures the difference in spreads that retail investors pay for conventional bonds, compared to other investors. An increase in the share of retail investors from 0% to 100% on conventional bonds instead is associated with an increase in the OAS by about 6bps, indicating that, in contrast to green bonds, retail investors tend to buy conventional bonds when they have higher spreads (or lower prices)[12].

A fair question is what drives this large increase in the holding share of retail investors. To our knowledge, there was no change in regulation or in investment practices that could explain this move. Therefore, we looked at whether the share of retail investors increased particularly strongly for specific types of bonds. Figure 8 depicts a striking finding: the share of retail investors increased markedly for green bonds issued by banks while remaining rather stable for most issuers. Interestingly, retail investors not only purchased green bonds issued by banks, but bank-issued bonds in general represent the largest share of retail investors' bond portfolios (see Figure 9 showing the total bond holdings of retail investors in Q4 2023 split by issuer sector).

Banks' proximity to their customers is a likely reason as it allows banks to sell bonds to smaller investors much easier. Unlike equity shares of companies, bonds are traded over the counter and are not listed on organised exchanges. Instead, to buy a bond, a buyer needs to either purchase the bond directly from a party selling it or, more commonly, buy it via a broker-dealer that acts as an intermediary. Banks, or their subsidiaries, often take on this function to intermediate bond market trading. In addition, customers with a regular deposit account can open a broker account directly with their bank to buy other financial securities. This setup makes it easier for banks to also advertise their own bonds directly to retail clients.

This may explain the large share of retail investor holdings specifically in bank bonds; however, it remains unclear why the retail share increased over time. It may be potentially driven by the rising share of bank bonds in the sample over time. Figures 8 and 10 show that not only did the share of retail investor holdings increase dramatically over time, but so did the share of bank bonds in the sample.

Issuance of green bonds by banks rose from 2019, which may be related to the proposal of the Sustainable Finance Disclosure Regulation (SFDR) in 2018 and its adoption in 2019 (see also Caramichael and Rapp (2024)). However, a particularly large jump in issuance is visible in

[12] There are numerous reasons why retail investors might be more inclined to buy bonds that exhibit higher spreads. First, this might be related to retail investors having a higher reservation return to shift from bank deposits to other types of assets during the negative interest rate environment corresponding to the most of observations in the sample. When interest rates were negative, remuneration on retail deposits was still above zero on most accounts, and thus relatively higher than for institutional investors. Alternative investments for retail investors thus needed to be somewhat higher for retail investors than institutional investors to entice them to switch. Second, given the size of the investment and lower financial literacy of retail compared to institutional investors, transaction costs might first need to be sufficiently offset for retail investors to buy a given bond. Bonds with lower returns might therefore be less attractive to retail than to institutional investors. Third, a recent strand of literature finds that retail investors often exhibit risk-seeking or even gambling-type behaviour that might also explain their higher search for yields (see ESMA (2022), Chiah and Zhong (2020) or Chiah et al. (2022).

2020, coinciding with the increase in the share of retail investors (see Figure 6) and the size of the greenium (see Figure 5). Some publications suggest that from 2018 banks started issuing green bonds targeted to retail investors (Climate Bond Initiative (2018a), Climate Bond Initiative (2018b)). Choi et al. (2020) document that investment decisions of retail investors are affected by their everyday life experience. Namely, the authors document that these investors sell more carbon-intensive firms when experiencing warmer local temperatures. This finding may suggest an alternative explanation why retail investors increased holdings in green bonds in mid-2020, at the climax of Covid-19 pandemic.

This jump in issuance, however, is not unique to banks' green bonds. In fact, overall bank bond issuance peaked in Q2 2020, as shown in Figure 11. This particular increase in volume was likely unrelated to the green bond market itself but rather seems to have been a response to the Covid-19 market shock. Nonetheless, this development had a large impact on the composition of the euro area green bond market.

The increase in the share of retail investors thus seems to have been initiated by the higher issuance of green (and conventional) bank bonds, which led to a greater prominence of banks in the green bond market and an associated increase in the greenium.

Overall, these observations suggest that higher retail investor demand partly drives the development of the greenium potentially due to a larger demand-supply mismatch and retail investors' tolerance to a lower return for environmentally-related projects. In a choice experiment and survey setups, Saravade et al. (2025) and Aruga (2025) indeed confirm that retail investors tend to favour green bonds and accept lower returns.

[PLACE FIGURES 8 AND 9 HERE]

[PLACE FIGURES 10 AND 11 HERE]

4.5 The greenium and the macroeconomic environment

The quarterly greenium estimate in Figure 5 shows that the greenium becomes smaller in 2022 and turns insignificant at the end of 2023. As the appearance of the greenium is primarily explained by retail investors' preferences, which tend to be sensitive to negative economic shocks (Döttling and Kim (2024), Bansal et al. (2022)), we can assume that the retail demand for green bonds and thus greenium change with the macroeconomic environment, depending, for example, on price of money and/or (un)certainty of economic conditions.

In the next step, we thus examine how the greenium interacts with the macroeconomic environment for bonds that have been purchased by retail investors. We explore influence of several different macroeconomic variables on the greenium as proposed in the literature. Specifically, we look at the euro area short-term interest rate, the crude oil price, the MSCI Europe equity index, the relative performance of European ESG equities (the difference in performance between the MSCI Europe ESG Leaders Index and the MSCI Europe Index), the VIX index and the intensity of Google searches for the terms “ESG” and “Green bond”.

The quarterly time series of these variables is depicted in Figure 12. We can see from this chart that many of the variables share common patterns with the greenium. On a quarterly basis, the strongest correlations with the greenium are found for the Google searches for the terms “ESG” and “Green bond”, the MSCI Europe Index and the VIX Index (see Table 5). However, the individual macro variables also exhibit high correlations with each other. In particular, the Google searches are highly correlated with each other, oil prices, interest rates and equity prices.

[PLACE FIGURE 12 HERE]

The quarterly correlations and time series of these variables thus suggest that many of these factors could influence or simply correlate with retail investor preferences, and therefore, the greenium, which motivates our next hypothesis.

Hypothesis 4: The greenium is influenced by the macroeconomic environment.

To formally test the hypothesis, we run the following regression,

$$OAS_{it} = \alpha_i + \beta Green_i + \nu macro_t + \mu \mathbf{Macro_t} \times \mathbf{Green_i} + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{5}$$

where $Macro_t$ are the individual macroeconomic variables comprising short-term euro area interest rate (3M Euribor), the oil price, the difference in returns between the MSCI ESG Europe Index and the MSCI Europe Index, and the VIX Index at daily frequency, as well as the Google Trends data for the terms “ESG” and “Green bond” at monthly frequency. As indicated by the set of macroeconomic control variables (M_t), the regressions always include all previously used macroeconomic variables, such as the 10-year Bund yield, 3M Euribor, and the VIX Index. As these control variables are not interacted with the green bond dummy variable (unless specified otherwise), they only control for the general level of spreads of both green and conventional bonds, without measuring the effect on the greenium specifically.

In addition to running the regressions on the individual macroeconomic variables, we also test all interaction terms simultaneously. As seen in Table 5, the individual macro variables are correlated with one-another, so there may be some collinearity among regressors. However, this also increases the risk of omitted variables bias if other variables are not accounted for, so we perform this test as a robustness check on the individual results.

As we are interested in the influence of macro variables on retail investors' preferences, we select bonds for which the average share of retail investor holdings accounts for at least 50% over the lifetime of the bond. This sample is relatively large, comprising 374 bonds, approximately half of the full sample of green and conventional bonds. For 350 of these 374 bonds, the other bond in the pair is also held by retail investors, so our sample is also quite balanced in terms of green and conventional retail bond holdings.

[PLACE TABLE 6 HERE]

The results are shown in Table 6. The main finding, consistent and statistically significant across all model specifications (including subsample regressions and triple interaction terms), is that rising interest rates are linked to a reduction in the greenium. As expected and suggested by other findings in the literature (Döttling and Kim (2024), Bansal et al. (2022)), retail investor preferences change with the tightness of financing conditions and the cost of funding. A modest, albeit visible, drop in the retail investor share starting from 2022 is also visible in Figures 6 and 9, and a similar pattern in the share of retail investments has been reported in the United States (see Chart A in Cera et al. (2023)). This might be because tighter financing conditions make it more costly (in terms of financing and opportunity costs) to invest in green bonds and, therefore, to finance investors' pro-social preferences.

Koijen and Yogo (2019) support this reasoning using a formal model that shows the dependence of the demand for an individual asset on the cross-elasticities and relative returns of other assets as well. Interestingly, Koijen and Yogo (2019) also find that almost half of the cross-sectional variance in asset returns is explained by household ownership, rather than large institutional investors, as the latter tend to be buy-and-hold investors. The increase in the price of an outside asset or financing option thus impacts the demand for a given asset and explains why the rise in interest rates would affect retail investors' preferences and demand for green bonds.

The next result that holds in all specifications is the correlation of the greenium with relative performance of ESG equity. This is consistent with Pastor et al. (2021) who document that green premium in equity and bond markets follows a similar trend.

None of the other variables suggested in the literature exhibit a consistent correlation with or systematic impact on the greenium. Oil prices, in particular, show no significant relationship with the greenium across all model specifications, contradicting the oil-driven greenium hypothesis proposed by Shi and Zhang (2024). This result is expected, as our analysis matches green and conventional bonds from the same issuer, implying that oil price changes would affect the issuer's default probability and thus both bond types equally.

The result for the "Google search" (the sum of searches for terms "ESG" and "Green bonds") interaction term is less intuitive. The significant and positive correlation in Column (6) indicates that the greenium falls when searches in these terms increase. This goes against expectations, and indeed the result does not seem robust, as it changes its sign and is no longer significant when accounting for all macroeconomic variables in Column (7). The result is not significant either in the robustness regressions with triple interaction terms (Table 12). This suggest that the previous result may be driven by omitted variable bias instead which is reduced by controlling for other variables.

Market uncertainty, measured by the VIX index, is statistically significant in most model specifications but becomes insignificant in the robustness test with triple interaction terms. The persistence of this result suggests an association between elevated market uncertainty and a stronger greenium for all bonds regardless of the holder, consistent with findings by Arat et al. (2023). This outcome is somewhat unexpected, as the flight-to-safety or flight-to-quality hypothesis predicts investors would favour conventional assets during periods of uncertainty (D'Amico et al. (2023)). However, Fatica et al. (2021) corroborate our finding, documenting investors' preference for holding green bonds during the pandemic, as shown by lower net sales of green bonds compared to equivalent conventional bonds. Furthermore, in our sample, the period of highest volatility aligns with increased retail investor participation in the green bond market and a corresponding shift in the greenium. To conclude, we document a relatively strong correlation between the greenium and market uncertainty, aligning with existing research.

However, we advise caution, as this finding may be specific to the nature of the shock and may not apply in other contexts.

In Table 12 we present robustness test with double interaction of greenium, retail holders and macro variables that confirm our main findings: retail investors' preferences change with the macroeconomic environment and in particular show a strong relationship with the level of interest rates. Outperformance of green bonds is correlated with outperformance of ESG equity and market uncertainty.

4.6 The Greenium and credibility of green bonds

Figure 1 shows that there is not only a changing dynamic of the greenium over time but also large heterogeneity in the cross-section. As recorded in Table 2, we find a greenium of about –3.7 bps in the baseline regression on our entire sample. However, the average greenium coefficient hides the heterogeneity in pricing for all green bond pairs observed in Figure 1. As documented previously in the literature (e.g., Fatica et al. (2021), Kapraun et al. (2021)), a larger greenium can be associated with higher credibility of a green bond. Our sample consists of green bonds issued by European agents and is thus already considered more credible than green bonds issued in other countries (Kapraun et al. (2021), Caramichael and Rapp (2024)). Despite that, we observe significant heterogeneity in spreads. Thus, we test if credibility is an important factor explaining the greenium in our sample of green bonds.

Greenwashing risks remain high, as market participants are concerned about the legitimacy of environmental claims made by issuers. By obtaining an external review attesting the successful implementation of the ICMA Green Bonds Principles, issuers can signal to investors a potential reduction in the greenwashing risk of the issued green bonds. Some issuers themselves may be perceived as more credible, e.g., by being part of market initiatives that provide credibility to their efforts. This section investigates the question of whether green bonds that are externally reviewed or issued by more credible issuers exhibit a larger greenium.

To assess the effect of green credibility, we start at the bond level. In particular, we are interested in whether bonds that fulfil all four ICMA GBP and have also been externally reviewed exhibit a larger greenium. Thus, we split our sample of green bonds into two categories: those green bonds which fulfil all four ICMA GBP and have also been externally reviewed, and those green bonds which have not been externally reviewed or fulfil only some of the ICMA GBP. As seen in Figure 2, the vast majority of green bonds are externally reviewed. This divides our sample of 447 unique green bonds into 8 non-reviewed green bonds and 439 that have been externally reviewed. Based on this division, we test the bond credibility hypothesis by enriching our econometric baseline regression with an external review dummy variable. The sample is extremely unbalanced and results should be taken with caution, but it allows us to see if we can confirm previous findings documented by the literature in our sample as well.

Hypothesis 5: Only green bonds with external review trade at a greenium.

$$OAS_{it} = \alpha_i + \beta Green_i + \zeta ER_i + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{6}$$

The external review variable (ER_i) as specified in Regression 6 is a dummy variable equal to 1 if the bond (i) is green, fulfils all four ICMA GBP and has been externally reviewed by a third party. It is 0 for all other bonds. As the variable can only be equal to 1 for bonds that are already green, it is also equal to the interaction term of the green bond dummy variable ($Green_i$) and the external review variable (ER_i). Thus, the coefficient ζ measures the difference in pricing between non-reviewed green bonds and green bonds that have been externally reviewed while β measures the difference in pricing between non-reviewed green and conventional bonds. The results of this regression can be found in Table 7.

[PLACE TABLE 7 HERE]

Indeed, we find that only externally reviewed green bonds trade at a statistically significant greenium, with -10.4 bps lower spreads than simple green bonds. The results, though not statistically significant, even hint that non-reviewed green bonds may trade at higher spreads than conventional bonds, which could indicate that the market punishes less credible green bonds. Overall, the results reject the hypothesis that there is no difference in the pricing of green bonds with different levels of credibility and suggest that only externally reviewed bonds enjoy a greenium on their pricing. However, the small sample size limits the robustness of the results and would preferably be tested on a larger sample to rule out other factors as possible drivers. Nonetheless, the results from our sample are consistent with the literature (Ehler and Packer (2017); Kapraun et al. (2021)) and suggest that our sample behaves similarly to those of other studies.

Hypothesis 6: Only green bonds issued by banks that are UNEP FI signatories trade at a *greenium.*

Now we are interested in whether there is evidence that the greenium is stronger for issuers that are more credible. We focus our analysis on the sample of bonds issued by banks, given their unique role in the development of the greenium we observed earlier.

As intermediaries, banks should issue green bonds only to finance green loans, but this cannot be assessed by investors directly. Instead, banks' credibility to fund green projects may be indicated by public commitments and, in particular, if banks are signatories of the United Nations Environmental Programme Finance Initiative (UNEP FI), as suggested by Fatica et al. (2021). The UNEP FI initiative was founded in 1992 and aims to mobilize private sector financing for sustainable development.[13] It is based on three principles: responsible banking, sustainable insurance, and responsible investment. In our sample, 60% of banks are UNEP FI signatories, which hints at the possibility that banks' green bonds are considered credible by investors. We test if this is reflected in the greenium, formulating the next hypothesis.

We first look at the sub-sample of bank bonds and repeat the baseline regression on the entire sample of bank bonds. The result can be found in Table 8, column (1). We find that overall, this sample exhibits a larger and highly significant greenium estimate of about -5.5 bps. Next, we define a UNEP FI dummy variable that is equal to 1 for bonds issued by UNEP FI banks and 0 otherwise. We then add this dummy variable to our baseline regression (Equation 2) and also interact it with the green dummy variable. This results in the following difference-in-difference specification, which measures the greenium of UNEP FI green bonds.

$$OAS_{it} = \alpha_i + \beta Green_i + \eta UNEPFI_{it} + \theta UNEPFI_{it} \times Green + \gamma X_{it} + \delta M_t + \epsilon_{it} \quad (7)$$

The coefficient of interest in this regression is the estimator ($\hat{\theta}$), which measures the difference in the greenium between green bonds issued by UNEP FI banks and those that are not. In other words, ($\hat{\theta}$) compares the sample of UNEP FI bond pairs and non-UNEP FI bond pairs to test whether there is a difference in the difference of the green and conventional bonds' OAS for the two samples.

[PLACE TABLE 8 HERE]

[13] See https://www.unepfi.org/ for further details.

As shown in Table 8, we observe that adding the UNEP FI variable changes the result of our greenium estimates. In fact, we find that the coefficient on the simple green bond dummy, captured by ($\hat{\beta}$), i.e., the difference in spreads between non-UNEP FI green bank bonds and conventional bank bonds, is much smaller and no longer significant. UNEP FI bonds, overall, trade at 36.3 bps lower spreads, on average. Finally, the parameter that we are most interested in, ($\hat{\theta}$), shows a significant difference of about –3.4 bps between the greenium for non-UNEP FI green bank bonds and UNEP FI green bonds. Therefore, we conclude that only green bonds issued by UNEP FI banks are perceived as more credible and thus exhibit a greenium.

To summarise, our tests showed that green credibility is a primary determinant of green bond pricing. In particular, we found the following results. First, only green bonds that are externally reviewed and thus signal a greater commitment to achieve a positive environmental impact exhibit a greenium. Second, only bank bonds issued by UNEP FI members trade at a greenium, since engaging in a certified third-party sustainability initiative lends additional credibility to the issuing banks. These findings underline that market participants require a regulatory standard for green bonds, such as EU Green Bond Standard, that will guarantee the quality and positive environmental performance of green bonds. Saravade et al. (2025) further highlight that most retail investors target labelled - green - bonds, however, rather insensitive to environmental performance of these bonds, thus stressing a scope for greenwashing in the market.

5 Robustness

We perform a series of robustness tests to address potential concerns and reject other explanations. First, we run robustness checks to account for imperfect matching in our sample by repeating Regression 2 on restricted samples across different dimensions. Table 9 shows the results of this exercise. In Column (1), we exclude any callable or convertible bonds from our regression to account for the effect of implied options that might bias our estimates of the OAS. We find a significant greenium of –4.1 bps in this sample. Next, in Column (2), we test whether the greenium differs across different levels of bond liquidity by adding an interaction of the green dummy with the bid-ask spread. We do not find any significant results, suggesting that the greenium is homogeneous across different levels of liquidity. Finally, we analyse in Column (3) whether the greenium differs based on the duration of a bond. The interaction term does not show any statistically significant result either.

[PLACE TABLE 9 HERE]

Moreover, we perform robustness checks on the matching precision. Column (4) in Table 9 shows the results of a regression on a sub-sample of 324 bonds, which are also matched exactly by the issue size. For this sample of pairs, we find a greenium of –6.2 bps. Matching the bonds exactly by the year in which they were issued (Column (5)) reduces the sample to 400 bonds, and the greenium remains significant at –1.9 bps. Finally, matching more closely by the coupon rate (Column (6)) and allowing a difference of at most 0.5 percentage points between pairs results in a sample of 462 bonds. The greenium is estimated at –3.3 bps. Overall, the results do not seem to be systematically driven by mismatches in the bond size, issue date, or coupon rate.

[PLACE TABLE 10 HERE]

The next set of robustness checks in Table 10 tests different specifications. First, we replace issuer fixed effects with issuer-time fixed effects and rerun the baseline regression of the greenium described in Equation 2. This means that macro variables are omitted, but the specification instead allows us to account for issuer-specific shocks over time that could potentially drive the greenium. As visible from Table 10, Column (1), the greenium estimate barely changes at –3.7 bps and preserves its statistical significance. In Column (2), we test if clustering the standard errors at the pair level would affect our results. The significance of the estimate does not change materially. We also test in Column (3) whether the effects of bond-level and issuer-level credibility can be statistically disentangled in the same regression. We find a statistically significant effect of both variables individually, although the small sample size of bonds without external review should be kept in mind. Excluding German issuers, as done in Column (4), addresses concerns about the representativeness of our sample with respect to the country of issuance, as the greenium remains significant. Finally, in Column (5), we test the results regarding the impact of retail investors' share by reducing the data to quarterly frequency, and the greenium in the baseline, as well as the interaction effect, remain significant.

[PLACE TABLE 11 HERE]

As we saw in Figure 8, there is a strong correlation between retail holdings and bonds issued by banks. This raises questions about the robustness of the findings regarding the role of retail investors in the evolution of the greenium over time, since two different results related to green bonds issued by banks can explain the greenium. The first is investor demand, and the second is UNEP FI membership. Therefore, we test if both results hold individually in the robustness test in Table 11. To ensure that we have no multicollinearity issues, we create two subsamples: one that only contains bonds issued by UNEP FI banks that were not bought by retail investors[14] and another that only contains bonds predominantly bought by retail investors but not issued by a UNEP FI bank[15].

We then rerun the same regression performed in Equation 3, interacting the green dummy variable with quarterly fixed effects to test if we find a time trend for bonds that are bought by retail investors and no time trend but a significant greenium for bonds issued by UNEP FI banks. As shown in Table 11, the results for the two samples are very different. Bonds that are purchased predominantly by retail investors but not issued by UNEP FI banks follow a time trend, as the greenium starts to appear at the end of Q2 2018 and then disappears again in Q2 2022. While the interaction term becomes significant again in Q4 2023, the size is not sufficiently large to offset the positive average greenium coefficient, which is also what we observe in the full sample. The size and dynamics of the greenium in this subsample closely follow the dynamics recorded in Table 3 and Figures 4 and 5 [16].

By contrast, bonds issued by UNEP FI banks that are not bought by retail investors have a significant greenium of 11.6 bps on the simple green coefficient. They do not exhibit any clear time trend. In fact, the greenium even disappears in Q3 2020 and Q4 2020 for this subsample, as indicated by the significant positive interaction terms in these two quarters, while the opposite is true for bonds bought by retail investors. When no quarterly interaction terms are included, the greenium estimate over the entire sample in Column (3) also remains robust and highly significant.

[14] We define this sample as bonds where the average retail share accounts for less than 2%. This applies to 123 bonds in the sample.

[15] We define this sample as bonds where the average retail share accounts for at least 50% and that have not been issued by a UNEP FI bank. This applies to 47 bonds in the sample.

[16] Although the greenium is net negative for this subsample before it becomes negative for the entire sample, this is likely related to the small weight of these bonds during that time period. Indeed, before Q2 2019, bonds bought by retail investors account for only 6% of the bonds in the full sample over that period, while this share increases dramatically to about 50% of all bonds with the increase in issuance.

Overall, the results confirm that it is not the UNEP FI designation that drives the time trend of the greenium but, indeed, the share of retail holdings. Moreover, the close alignment with the dynamics of the euro area short-term interest rate provides more evidence that monetary policy tightening led to a change in retail investors' preferences.

[PLACE TABLE 12 HERE]

We assess the robustness of our findings in the context of the macroeconomic environment, using the full sample and interacting all variables with the retail holding share. The results confirm that the relationships between interest rates, ESG equity outperformance, and green preferences are unique to retail investors. The coefficients on the triple interaction term—combining the green bond dummy, the retail investor dummy, and the respective macroeconomic variables—are statistically significant, with consistent signs and comparable magnitudes.

Furthermore, interest rates exhibit a negative correlation, and ESG equity outperformance a positive correlation, with conventional bond spreads held by retail investors. These findings indicate that tighter financial conditions influence retail investors' preferences for conventional bonds as well, suggesting that this effect may be even more pronounced for green bonds, given the higher cost of financing green preferences for retail investors.

The increase of the greenium in times of uncertainty, as indicated by the interaction of the green dummy variable and the VIX Index, applies to all green bonds, regardless of the holder.

Column (2) shows that when not accounting for the impact of macro-factors directly through retail investors, the retail share alone remains a significant determinant of the greenium. Compared to the results in Table 4, the coefficient is just about 0.2 basis points smaller. Given this very small difference between the two coefficients, the retail channel seems robust.

Overall, the robustness check highlights a common trend shaping retail investors' preferences, which is also reflected in the greenium, further supporting our hypothesis that the macroeconomic environment influences the greenium.

Finally, we test the time trend of the greenium using a different specification. Instead of running the regression on bond-level observations, we look at the pair level. For this, we merge the daily observations of all green bonds with the daily observations of their conventional counterparts. We then compute the difference in any numeric variables and rerun the regression on quarterly sub-samples. Instead of including a green bond dummy, we regress the daily difference in OAS for each pair on a constant and the difference in numerical control variables. In this case, the constant estimates the greenium. The results of this exercise are plotted in Figure 13. We find a similar time trend in this regression, and the greenium becomes consistently statistically significant in the second quarter of 2020.

[PLACE FIGURE 13 HERE]

To summarise, the robustness tests do not suggest that our results were biased by other factors. In particular, factors such as embedded options, duration, liquidity, or mismatching do not seem to play a role in the greenium. Stricter matching on the amount issued, issue date, or coupon rate also do not significantly change the results. Different specifications also confirm the dynamics of the greenium, the role of retail investors and the relationship with the macroeconomic environment.

6 Conclusion

This study investigates the presence and dynamics of the greenium, a price premium associated with green bonds, for European issuers from 2016 to 2023. While green bonds have gained significant traction as a financing instrument for sustainable projects, the existence and magnitude of the greenium have been subject to debate.

The analysis of green bonds issued by European entities from 2016 to 2023 shows a statistically significant greenium, averaging -3.7 basis points, indicating that the market may associate these bonds with Europe's environmental policies. This greenium, however, exhibits notable temporal and cross-sectional heterogeneity. The greenium was largely insignificant before 2020, peaked significantly from 2020 to early 2022, and diminished thereafter, influenced potentially by macroeconomic challenges such as the energy crisis, rising inflation, and monetary tightening. Retail investors emerged as a key driver of the time trend, particularly increasing their holdings in bank-issued green bonds that led to a larger greenium of -6.4 basis points. This retail demand, sensitive to macroeconomic conditions like rising interest rates, underscores the interplay between investor behavior, market dynamics, and the greenium's evolution.

Credibility appears as an important factor in the green bond market, with bonds featuring external reviews and those issued by environmentally committed banks, such as UNEP FI members, commanding higher greeniums of -4.1 and -5.7 basis points, respectively.

This research contributes significantly to the literature by extending the greenium analysis to a period of macroeconomic turbulence, highlighting the role of retail investor demand, and reinforcing the importance of credibility in bond pricing. The findings suggest that while the European green bond market benefits from strong regional environmental policies, the greenium is not a static phenomenon but one shaped by temporal market conditions and investor trust. These insights are critical for policymakers and issuers aiming to enhance the appeal and efficacy of green bonds in financing the transition to a low-carbon economy. They emphasize the importance of investor confidence and the role of regulatory frameworks, such as the EU Green Bond Standard, in fostering a robust and credible green bond market. A well-defined regulatory framework is crucial for ensuring that green bond proceeds are used effectively to support the transition to a low-carbon economy and maintaining investor confidence in the integrity of the green bond market.

References

Abidi, N. and I. Miquel-Flores (2018). Who benefits from the corporate qe? a regression discontinuity design approach. *ECB Working Paper Series* (2145).

Altman, E. I. (1968). Financial ratios, discriminant analysis and the prediction of corporate bankruptcy. *The Journal of Finance 23*(4), 589–609.

Andersen, S., D. Chebotarev, F. Z. Filali Adib, and K. M. Nielsen (2023). Rich and responsible: Is esg a luxury good? *Available at SSRN 4615424*.

Arat, E., B. Hachenberg, F. Kiesel, and D. Schiereck (2023). Greenium, credit rating, and the covid-19 pandemic. *Journal of Asset Management 24*(7), 547–557.

Aruga, K. (2025). Are retail investors willing to buy green bonds? a case for japan. *Journal of Sustainable Finance & Investment 15*(2), 388–402.

Azad, S., S. Tulasi Devi, and A. K. Mishra (2024). Investing in our planet: Examining retail investors' preference for green bond investment. *Business Strategy and the Environment 33*(6), 5151–5173.

Baker, M., D. Bergstresser, G. Serafeim, and J. Wurgler (2018). Financing the response to climate change: The pricing and ownership of us green bonds. Technical report, National Bureau of Economic Research.

Bansal, R., D. Wu, and A. Yaron (2022). Socially responsible investing in good and bad times. *The Review of Financial Studies 35*(4), 2067–2099.

Bao, J., J. Pan, and J. Wang (2011). The illiquidity of corporate bonds. *Journal of Finance 66*(3), 911–946.

Bauer, R., T. Ruof, and P. Smeets (2021). Get real! individuals prefer more sustainable investments. *The Review of Financial Studies 34*(8), 3976–4043.

Ben-Rephael, A., S. Kandel, and A. Wohl (2012). Measuring investor sentiment with mutual fund flows. *Journal of financial Economics 104*(2), 363–382.

BenSlimane, M., V. Mahtani, and D. D. Fonseca (2020). Facts and fantasies about the green bond premium. *Amundi Working Paper* (102).

Bond, P., A. Edmans, and I. Goldstein (2012). The real effects of financial markets. *Annual Review of Financial Economics 4*, 339–360.

Bondioli, M., Goldberg, N. M., Hu, C. Li, O. Maalaoui, and H. Stein (2021). The bloomberg corporate default risk model (drsk) for private firms. *Quantitative Risk Analytics, Bloomberg L.P.*.

Bondioli, M., H. N. Goldberg, M., C. Li, O. Maalaoui, and H. Stein (2021). The bloomberg corporate default risk model (drsk) for public firms. *Quantitative Risk Analytics, Bloomberg L.P.*.

Caramichael, J. and A. C. Rapp (2024). The green corporate bond issuance premium. *Journal of Banking Finance 162*, 107–126.

Carbone, s., M. Giuzio, S. Kapadia, J. S. Kramer, K. Nyholm, and K. Vozian (2021). The low-carbon transition, climate commitments and firm credit risk. *ECB Working Paper series 2631*.

CBI (2024). Sustainable debt. global state of the market. Technical report, Climate Bond Initiative.

Ceccarelli, M., S. Ramelli, and A. F. Wagner (2024). Low carbon mutual funds. *Review of Finance 28*(1), 45–74.

Cera, K., A. Pietsch, and A. Sowinski (2023). Financial stability considerations arising from the digitalisation of financial services. *Financial Stability Review* (May).

Chiah, M., X. Tian, and A. Zhong (2022). Lockdown and retail trading in the equity market. *Journal of Behavioral and Experimental Finance 33*.

Chiah, M. and A. Zhong (2020). Trading from home: The impact of covid-19 on trading volume around the world. *Finance Research Letters 37*.

Choi, D., Z. Gao, and W. Jiang (2020). Attention to global warming. *The Review of Financial Studies 33*(3), 1112–1145.

Climate Bond Initiative (2018a). Green bonds: The state of the market 2018.

Climate Bond Initiative (2018b). Green Bond Fact Sheet - UmweltBank AG.

Coudert, V., C. Couharde, and V. Mignon (2011). Exchange rate volatility across financial crises. *Journal of Banking Finance 35*(11), 3010–3018.

Coudert, V. and D. Salakhova (2020). Do mutual fund flows affect the french corporate bond market? *Economic Modelling* (87).

De Santis, R., A. Geis, A. Juskaite, and L. Vaz Cruz (2018). The impact of the corporate sector purchase programme on corporate bond markets and the financing of euro area non-financial corporations. *ECB Economic Bulletin* (3).

Delis, M. D., K. de Greiff, M. Iosifidi, and S. Ongena (2021). Being stranded with fossil fuel reserves? climate policy risk and the pricing of bank loans. *Swiss Finance Institute Research Paper 18*(10).

Döttling, R. and S. Kim (2024). Sustainability preferences under stress: Evidence from covid-19. *Journal of Financial and Quantitative Analysis 59*(2), 435–473.

Duffie, D., L. Saita, and K. Wang (2007). Multi-period corporate default prediction with stochastic covariates. *Journal of Financial Economics 83*(3), 635–665.

D'Amico, S., J. Klausmann, and N. Pancost (2023). The benchmark greenium. *mimeo*.

Ehler, T. and F. Packer (2017). Green bond finance and certification. *BIS Quarterly Review, September 2017*.

ESMA (2022). Final report – on the european commission mandate on certain aspects relating to retail investor protection.

Fatica, S., R. Panzica, and M. Rancan (2021). The pricing of green bonds: Are financial institutions special? *Journal of Financial Stability 54*(c).

Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics 142*(2), 499–516.

Han, S. and H. Zhou (2016). Effects of liquidity on the non-default component of corporate yield spreads: evidence from intraday transactions data. *Quarterly Journal of Finance 6*, 129–178.

Huang, Z. (1997). Clustering large data sets with mixed numeric and categorical values. *Proceedings of the First Pacific Asia Knowledge Discovery and Data Mining Conference*.

Huang, Z. (1998). Extensions to the k-means algorithm for clustering large data sets with categorical values. *Data Mining and Knowledge Discovery* (2).

IFC and Amundi (2024). Emerging market green bonds.

Kapraun, J., C. Latino, C. Scheins, and C. Schlag (2021). Which bonds trade at a green bond premium? *mimeo*.

Karpf, A. and A. Mandel (2017). Does it pay to be green? *Unpublished working paper. Pantheon-Sorbonne University*.

Koijen, R. S. J. and M. Yogo (2019). A demand system approach to asset pricing. *Journal of Political Economy 127*(4), 1475–1515.

Koziol, C., J. Proelss, P. Roßmann, and D. Schweizer (2022). The price of being green. *Finance Research Letters 50*, 103285.

Larcker, D. and E. Watts (2020). Where is the greenium? *Accounting Economics* (69).

Li, Q., E. M. Watts, and C. Zhu (2024). Retail investors and esg news. *Journal of Accounting and Economics 78*(2-3), 101719.

Longstaff, F., S. Mithal, and E. Neis (2005). Corporate yield spreads: Default risk or liquidity? new evidence from the credit default swap market. *Journal of Finance 60*(5), 2213–2253.

Pastor, L., R. F. Stambaugh, and L. A. Taylor (2021). Dissecting green returns. *mimeo*.

Rey, H. (2016). International channels of transmission of monetary policy and the mundellian trilemma. *IMF Economic Review 64*(1), 6–35.

Riedl, A. and P. Smeets (2017). Why do investors hold socially responsible mutual funds? *the Journal of Finance 72*(6), 2505–2550.

Sangiorgi, I. and L. Schopohl (2021). Why do institutional investors buy green bonds: Evidence from a survey of european asset managers. *International Review of Financial Analysis 75.*

Saravade, V., O. Weber, and A. Vitalis (2025). To label or not? a choice experiment testing whether labelled green bonds matter to retail investors. *Humanities and Social Sciences Communications 12*(1), 1–16.

Shi, Z. and S. Zhang (2024). Oil-driven greenium. *Fisher College of Business Working Paper* (2024-03), 24.

Subran, L., R. Fortes, J. Groeschl, A. Jobst, M. Kreuzberger, M. Martini, and N. Temuege (2023). Toasted, roasted and grilled? walking the talk on green monetary policy. *mimeo*.

Tang, D. and Y. Zhang (2018). Do shareholders benefit from green bonds?

Van der Beck, P. (2021). Flow-driven esg returns. Technical report, Swiss Finance Institute.

Yu, Q., E. C.-M. Hui, and J. Shen (2024). The real impacts of third-party certification on green bond issuances: Evidence from the chinese green bond market. *Journal of Corporate Finance 89*.

Zerbib, O. (2019). The effect of pro-environmental preferences on bond prices: evidence from green bonds. *Journal of Banking Finance 98*, 39–60.

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7 Appendix

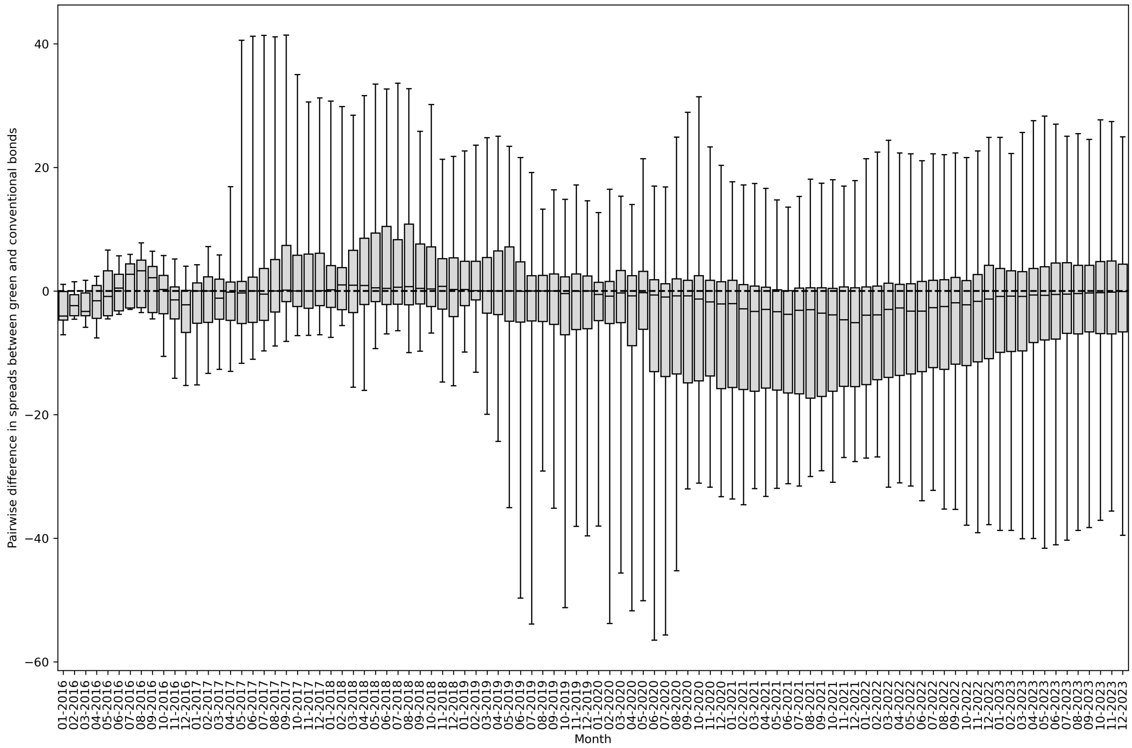

Figure 1: Distribution of spreads between matched green and conventional euro area bonds
The Figure shows the distribution of the average monthly difference in option-adjusted spreads (OAS) between matched green and conventional bonds for a sample of 894 euro area bonds, i.e. 447 pairs of 79 unique issuers between 2016 and 2023. The line marks the median difference, and the box corresponds to the interquartile range. Whiskers indicate the 5th and 95th percentiles.

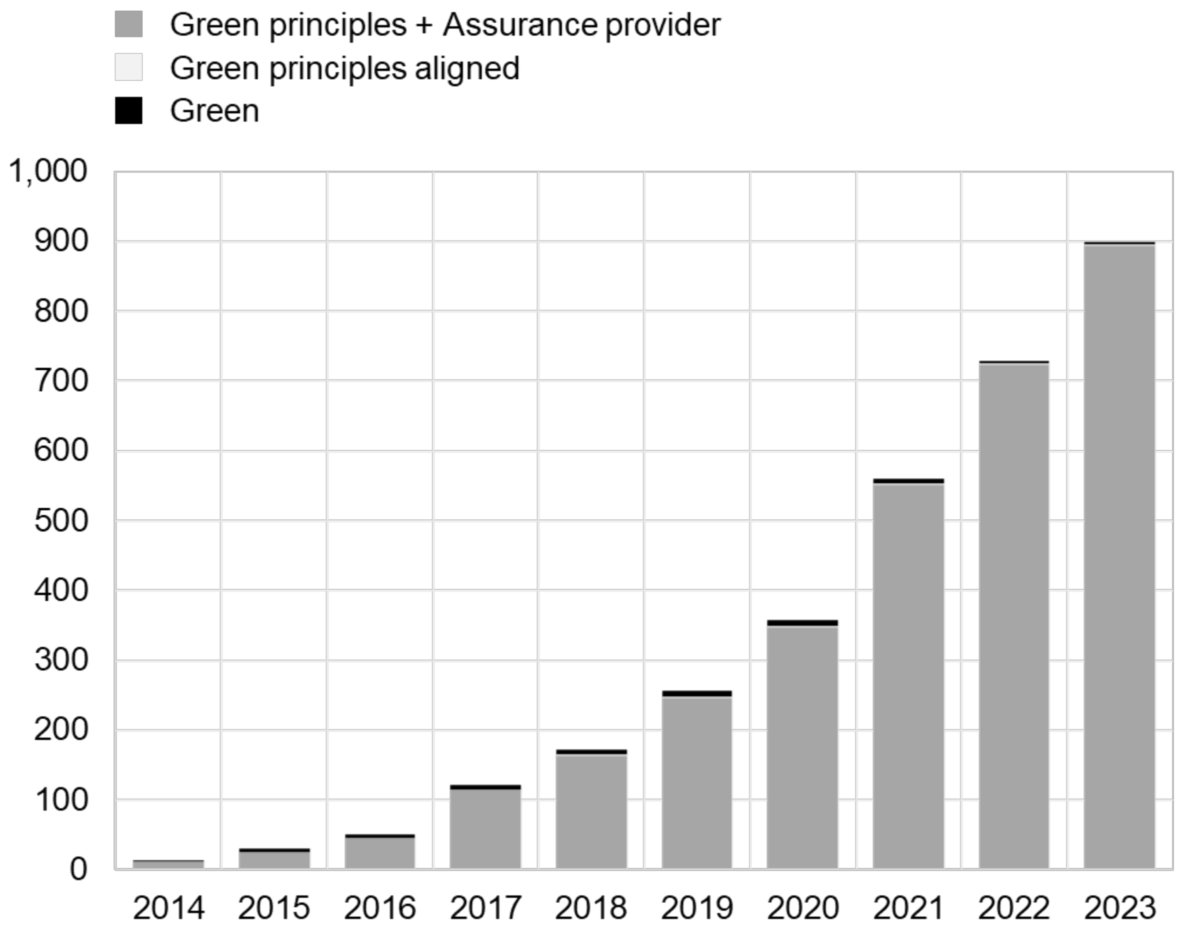

Figure 2: Total amount outstanding of euro area green bonds by classification
Full sample of bonds classified as green and active in Bloomberg, between 2014 and 2023, issued by euro area issuers. "Green" indicates that a bond is classified as green but does not fulfill all ICMA Green Bonds Principles. "Green principle aligned" indicates that all ICMA Green Bond Principles are met. "Green principles + Assurance provider" means that a bond fulfills all principles and has also been externally reviewed.

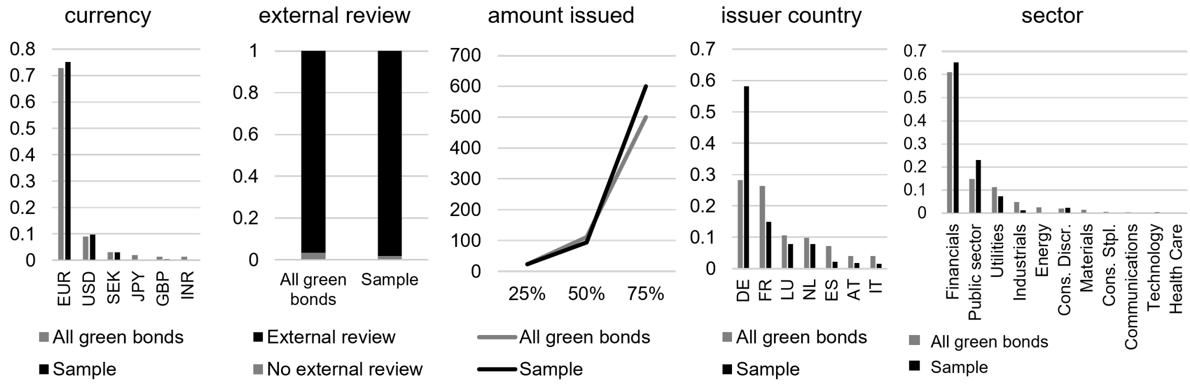

Figure 3: Descriptive statistics of all euro area green bonds and matched sample
The chart compares the descriptive statistics of the sample of 447 green bonds used for the analysis in this paper with the full universe of euro area green bonds available in Bloomberg. The first, second, fourth, and fifth charts show the respective share of bonds in the sample and in Bloomberg, for a given category. The third chart shows the first to third quartile of the amount issued for green bonds in the sample versus all green bonds in Bloomberg.

	Green mean	Conventional mean	Difference	Standard error	t-statistic	Observations
Senior	0.998	0.998	0.000	(0.003)	0.00	894
log(amount issued)	18.597	18.324	-0.273	(0.141)	-1.938	894
Couponrate	1.459	1.569	0.110	(0.108)	1.01	894
ECB eligible	0.373	0.359	-0.013	(0.032)	-0.41	894
Embedded option	0.172	0.174	0.002	(0.025)	0.08	894
OAS	99.341	103.239	3.898^{***}	(0.189)	20.66	518,868
Duration	5.850	5.616	-0.234^{***}	(0.009)	-26.82	518,868
Bid-ask spread	0.436	0.442	0.006^{***}	(0.001)	7.29	518,868

Table 1: Summary Statistics of green and conventional bonds in the sample

The Table compares the summary statistics of the green and conventional bonds in the sample used in this study, comprising 447 green and 447 matched conventional bonds. The variables "Senior" and "Embedded option" are coded as dummy variables, while all other variables are continuous. The first five variables are constant across time and therefore tested on a static sample without duplicated bond-level observations. The last three variables vary over time and are tested on the full panel dataset.

	(1) Option-Adjusted Spread	(2) Option-Adjusted Spread
Green		-3.717***
		(1.399)
10Y Bund yield	33.334***	33.316***
	(5.309)	(5.273)
3M Euribor yield	-8.015***	-7.982***
	(0.933)	(0.944)
VIX Index	1.370***	1.370***
	(0.343)	(0.343)
Default probability	629.337**	631.325**
	(313.869)	(314.125)
Bid-ask spread	7.851	7.451
	(17.453)	(17.617)
ECB eligible	-20.869***	-20.410***
	(7.462)	(7.448)
Log(amount issued)	-2.797**	-2.574**
	(1.240)	(1.285)
Couponrate	3.315***	3.109**
	(1.186)	(1.228)
Duration	3.113**	3.181**
	(1.193)	(1.218)
Constant	78.373***	75.921***
	(26.008)	(27.234)
Issuer FE	Yes	Yes
Currency FE	Yes	Yes
Seniority FE	Yes	Yes
Debt type FE	Yes	Yes
Embedded option FE	Yes	Yes
Observations	517188	517188
R^2	0.774	0.775
Adjusted R^2	0.774	0.775

Standard errors in parentheses, clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Greenium estimate across all bonds
The Table presents results for Hypothesis 1: Green bonds of European issuers trade at a greenium on the full sample over the period 2016-2023. The regression is specified in Equation 2. The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 984 matched green and conventional bonds of euro area issuers between 2016 and 2023. "Green" is a dummy variable equal to 1 if the bond is classified as green and 0 if the bond is conventional.

	Option-Adjusted Spread	
Green	-9.053*	(4.576)
Green × Q2 2016	1.324	(1.681)
Green × Q3 2016	3.087	(2.497)
Green × Q4 2016	3.228	(3.288)
Green × Q1 2017	5.749	(3.960)
Green × Q2 2017	7.932	(4.893)
Green × Q3 2017	10.769**	(5.245)
Green × Q4 2017	12.152**	(5.155)
Green × Q1 2018	15.334**	(5.977)
Green × Q2 2018	12.767***	(4.813)
Green × Q3 2018	14.735***	(5.181)
Green × Q4 2018	13.393**	(5.353)
Green × Q1 2019	12.865**	(5.296)
Green × Q2 2019	9.746*	(4.967)
Green × Q3 2019	6.649	(4.935)
Green × Q4 2019	7.129	(4.701)
Green × Q1 2020	6.731	(4.860)
Green × Q2 2020	3.933	(4.695)
Green × Q3 2020	3.825	(3.791)
Green × Q4 2020	4.223	(3.465)
Green × Q1 2021	2.691	(3.695)
Green × Q2 2021	1.698	(3.490)
Green × Q3 2021	2.853	(3.489)
Green × Q4 2021	3.657	(3.521)
Green × Q1 2022	3.503	(3.471)
Green × Q2 2022	3.940	(3.466)
Green × Q3 2022	5.146	(3.734)
Green × Q4 2022	5.351	(4.135)
Green × Q1 2023	6.159	(4.417)
Green × Q2 2023	5.993	(4.418)
Green × Q3 2023	6.225	(4.831)
Green × Q4 2023	7.611	(5.230)
Controls	Yes	
Issuer FE	Yes	
Currency FE	Yes	
Seniority FE	Yes	
Debt type FE	Yes	
Embedded option FE	Yes	
Observations	517254	
R^2	0.816	
Adjusted R^2	0.816	

Standard errors in parentheses, clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Greenium over time
The Table presents results for Hypothesis 2: In the euro area's secondary bond market, the greenium varies over time, being economically and statistically significantly negative in some periods but not in others. The regression is specified in Equation 3. The dependent variable is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 984 matched green and conventional bonds of euro area issuers between 2016 and 2023. "Green" is a dummy variable equal to 1 if the bond is classified as green and 0 if conventional. The Green dummy is interacted with a dummy variable for each quarter of the dataset. The prevalent greenium in a given quarter can be interpreted as the sum of the "Green" coefficient and the interaction term for the respective quarter.

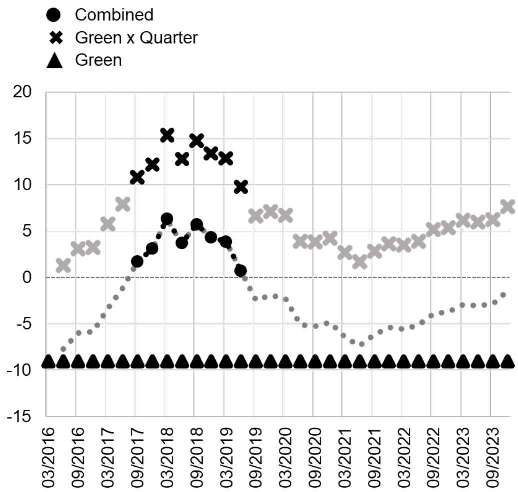

Figure 4: Green coefficient and coefficients on quarterly interaction terms
Figure 4 shows the estimated coefficient on the green bond dummy and the interaction term for a sample of 984 euro area matched green and conventional bonds between 2016 and 2023, as presented in Table 3. The combined effect is the sum of the two coefficients for each quarter. Significant coefficients are indicated in black.

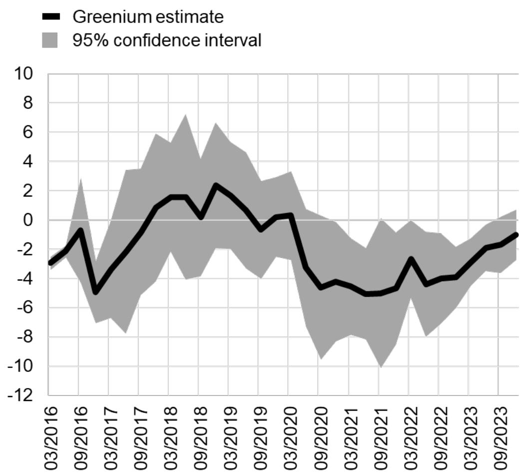

Figure 5: Green coefficient and confidence interval on quarterly subsamples
Figure 5 shows the estimated coefficient on the green bond dummy variable and the 95% confidence interval, from a regression on quarterly subsamples. The regression specified in Equation 2 is repeated on the daily panel dataset for each quarter. The individual coefficients are stored and plotted in this Figure.

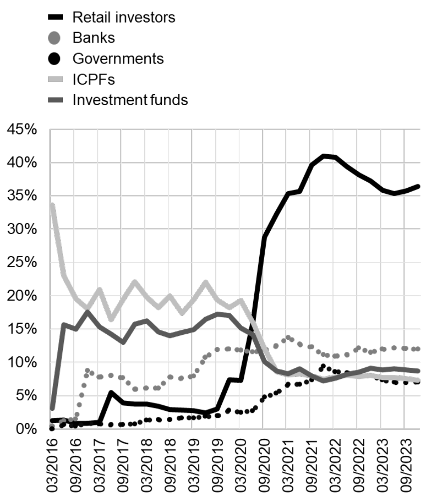

Figure 6: Average holding share of euro area investors of bonds in the sample
Figure 6 shows the average share of each euro area investor sector across all 984 matched green and conventional bonds in the sample, based on ECB Securities Holdings Statistics by Sector data. The holding share is computed as the amount of a bond held by a given investor, divided by the total amount outstanding of a given bond. A simple average per quarter is displayed.

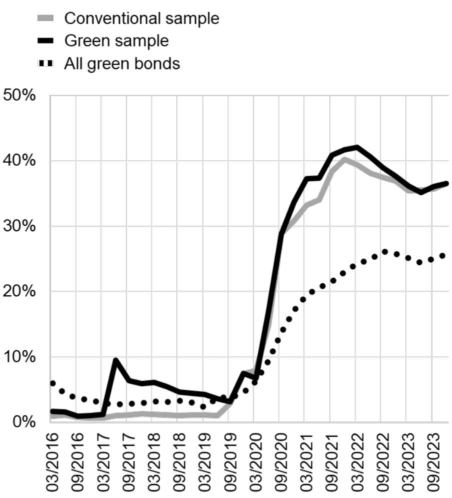

Figure 7: Average retail share for green and conventional bonds and all green bonds
Figure 7 shows the average share of euro area retail investors across all green and conventional bonds in the sample of matched green and conventional bonds and of all euro area green bonds registered in the Bloomberg database. Holdings data is based on ECB Securities Holdings Statistics by Sector data. The holding share is computed as the amount of a bond held by a given investor, divided by the total amount outstanding of a given bond. A simple average per quarter is displayed in the Figure.

	(1)
	Option-adjusted spread
Green	-3.245***
	(1.106)
Retail share	5.974***
	(1.986)
Green × Retail share	-3.173**
	(1.304)
EA share	1.599
	(6.698)
Controls	Yes
Issuer FE	Yes
Year FE	Yes
Currency FE	Yes
Seniority FE	Yes
Debt type FE	Yes
Embedded option FE	Yes
Observations	469854
R^2	0.770
Adjusted R^2	0.770

Standard errors in parentheses, clustered at the bond, issuer and quarter level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Greenium for bonds held by retail investors

The Table presents result for Hypothesis 3: The greenium dynamics in the euro area secondary bond market is driven in part by retail investor demand. The regression is specified in Equation 4. The dependent variable is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 800 matched green and conventional bonds of euro area issuers between 2016 and 2023. "Green" is a dummy variable equal to 1 if the bond is classified as green and 0 if conventional. The Green dummy is interacted with the holding share of retail (households and non-financial corporate) investors in a given quarter. "EA share" indicates the total share of euro area retail investors.

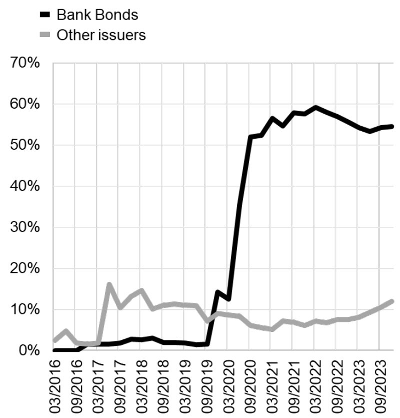

Figure 8: Retail investors' holding share of green bonds, by issuer sector
The Figure shows the average share of euro area retail investors by issuer sector, split by banks and other issuing sectors. The sample of bonds comprises 447 green bonds studied in this paper, holdings data are based on ECB Securities Holdings Statistics by Sector data. The holding share is computed as the amount of a bond held by retail investors, divided by the total amount outstanding of a given bond. A simple average per quarter and bank/other issuer sector is displayed in the Figure.

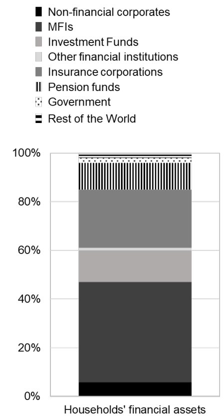

Figure 9: Retail investors' total bond holdings, by issuer sector (Q4 2023)
The figure shows the aggregate bond portfolio of all euro area households by the issuing sector, based on ECB and Eurostat sectoral accounts data.

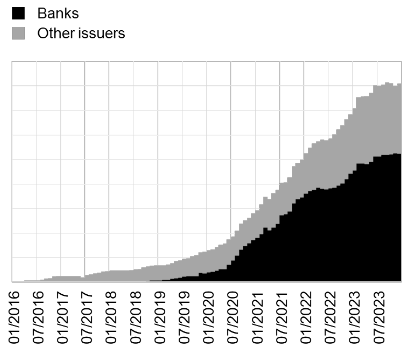

Figure 10: Number of outstanding bonds in sample issued by banks vs other issuers
The Figure shows the number of outstanding bonds in a given quarter issued by banks or other sectors for the sample of 984 matched euro area green and conventional bonds studied in this paper.

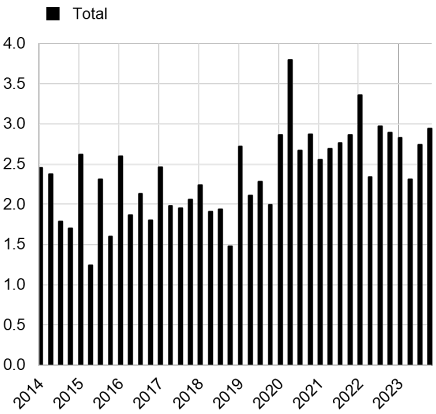

Figure 11: Total issuance of euro area bank bonds (€billions)
The Figure shows primary issuance volumes of all bonds (of any type) issued in a given quarter by euro area banks, based on Dealogic data. The sample is not restricted beyond the issuer, i.e., it represents the full universe of euro area bank bonds.

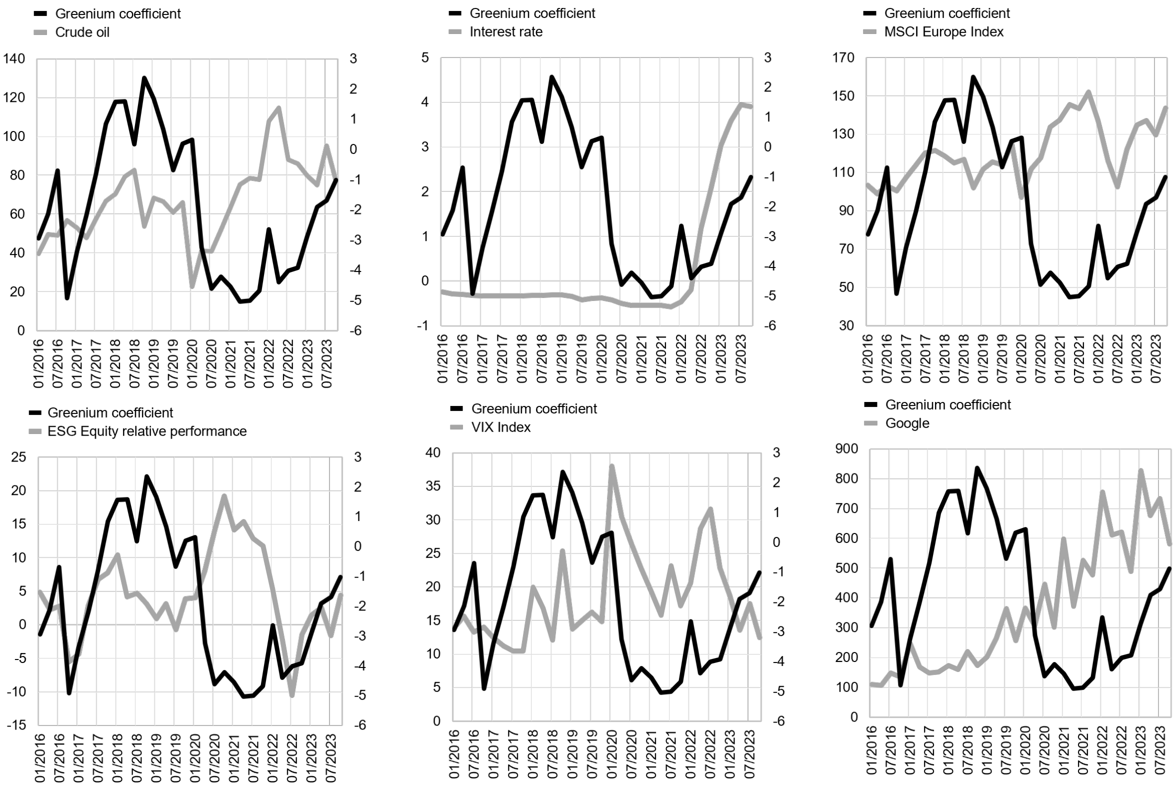

Figure 12: Quarterly macro variables and the Greenium estimate
The Figure shows the value of the respective macro variable at quarterly frequency and the greenium coefficient obtained from the regression on quarterly subsamples as specified in Equation 2 of the OAS on the "Green" dummy variable (also displayed in Figure 5). "ESG Equity relative performance" is the difference in return between the MSCI Europe ESG Leader and MSCI Europe Index. "Google" is a measure of search intensity captured by Google trends for the terms "Green bond" and "ESG".

	Greenium coefficient	Crude oil	Interest rate	MSCI Europe Index	ESG Equity. rel. perf.	VIX Index	Google
Greenium coefficient	1.00						
Crude oil	-0.13	1.00					
Interest rate	-0.03	0.37	1.00				
MSCI Europe Index	-0.34	0.49	0.31	1.00			
ESG Equity rel. perf.	-0.14	-0.22	-0.34	0.55	1.00		
VIX index	-0.22	-0.05	-0.08	-0.18	0.01	1.00	
Google	-0.43	0.60	0.61	0.59	-0.06	0.34	1.00

Table 5: Correlation Matrix
The table shows the pair-wise correlations between the quarterly time-series of the respective macro variables and the quarterly greenium coefficient. Macro variables are at quarterly frequency, and the greenium coefficient is obtained from a regression on quarterly subsamples, as specified in Equation 2 of the OAS on the "Green" dummy variable (also displayed in Figure 5). "ESG Equity relative performance" is the difference in return between the MSCI Europe ESG Leader and MSCI Europe Index. "Google" is the measure of search intensity captured by Google trends for the terms "Green bond" and "ESG".

	(1) Oil price	(2) Interest rate	(3) MSCI Europe Index	(4) ESG Equity rel. perf.	(5) VIX index index	(6) Google trends	(7) All macro factors
Green	-14.848**	-7.925***	-31.144***	-2.069	1.723	-17.199***	13.556
	(5.804)	(1.722)	(6.044)	(2.054)	(2.463)	(3.233)	(9.112)
Green × Oil	0.128						0.031
	(0.076)						(0.035)
Green × 3M Euribor		2.512***					1.191***
		(0.466)					(0.387)
Green × MSCI Europe			0.220***				-0.087
			(0.057)				(0.060)
Green × MSCI rel. perf.				-0.508**			-0.416*
				(0.212)			(0.237)
Green × VIX Index					-0.299***		-0.352**
					(0.075)		(0.161)
Green × Google						0.022***	-0.004
						(0.005)	(0.004)
Oil	0.436***						0.552***
	(0.133)						(0.151)
3M Euribor	0.700	-9.231***	-8.865***	5.650**	-8.048***	-8.058***	12.284***
	(1.659)	(1.407)	(1.355)	(2.649)	(1.502)	(1.566)	(3.310)
MSCI Europe Index			-0.573**				-0.485
			(0.230)				(0.322)
MSCI rel. perf.				-3.833***			-3.349***
				(0.647)			(0.524)
VIX Index	2.175***	1.841***	1.362***	0.643**	1.980***	1.965***	0.899***
	(0.473)	(0.449)	(0.276)	(0.293)	(0.462)	(0.455)	(0.195)
Google						-0.039***	-0.017***
						(0.006)	(0.004)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Issuer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Seniority FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Debt type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Embedded option FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	195267	195335	195335	195335	195335	195335	195267
R^2	0.725	0.720	0.721	0.763	0.719	0.722	0.769
Adjusted R^2	0.725	0.720	0.721	0.763	0.719	0.722	0.769

Standard errors in parentheses, clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Macro-factors and the greenium for bonds held by retail investors

The Table presents results for Hypothesis 4: The greenium is influenced by the macroeconomic environment. The regression is specified in Equation 5. The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 374 matched euro area green and conventional bonds between 2016 and 2023, that are predominantly held by retail investors (the average retail holding share of a bond is at least 50%). "ESG Equity relative performance" is the difference in return between the MSCI Europe ESG Leader and the MSCI Europe Index. "Google" is the measure of search intensity captured by Google trends for the terms "Green bond" and "ESG".

	(1) Option-adjusted spread
Green	6.372
	(4.226)
External review	-10.442**
	(4.361)
Controls	Yes
Issuer FE	Yes
Currency FE	Yes
Seniority FE	Yes
Debt type FE	Yes
Embedded option FE	Yes
Observations	517188
R^2	0.775
Adjusted R^2	0.775

Standard errors in parentheses, clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Greenium of externally reviewed bonds
The Table presents results for Hypothesis 5: Only green bonds with external review trade at a greenium. The regression is specified in Equation 6. The dependent variable is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 984 matched green and conventional bonds of euro area issuers between 2016 and 2023. "Green" is a dummy variable equal to 1 if the bond is classified as bond and 0 if conventional. "External review" is a dummy variable indicating if a green bond satisfies all ICMA Green Bond Principles and has also been reviewed by a third party, in which case it is equal to 1 and 0 otherwise.

	(1) Bank bonds	(2) Bank bonds
Green	-5.559***	-2.480
	(1.226)	(1.854)
UNEP FI		-36.316***
		(6.610)
Green × UNEP FI		-3.413**
		(1.336)
Controls	Yes	Yes
Issuer FE	Yes	Yes
Currency FE	Yes	Yes
Seniority FE	Yes	Yes
Debt type FE	Yes	Yes
Embedded option FE	Yes	Yes
Observations	309504	309504
R^2	0.719	0.723
Adjusted R^2	0.719	0.723

Standard errors in parentheses, clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Greenium for bank bonds and UNEP FI banks
The Table presents results for Hypothesis 6: Only green bonds issued by banks that are UNEP FI signatories trade at a greenium. The regression is specified in Equation 7. The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 564 matched green and conventional bonds, issued by euro area banks, between 2016 and 2023. "Green" is a dummy variable equal to 1 if the bond is classified as green and 0 if conventional. "UNEPFI" is a dummy variable indicating if the bank is part of the United Nations Environment Program Finance Initiative (UNEP FI).

	(1) Straight bonds	(2) Bid-ask	(3) Duration	(4) Amount issued	(5) Issuedate	(6) Couponrate
Green	-4.063**	-4.913***	-4.288**	-6.153***	-1.879**	-3.277***
	(1.567)	(1.558)	(2.118)	(1.225)	(0.876)	(1.134)
Green × Bid-ask spread		2.732				
		(5.052)				
Green × Duration			0.100			
			(0.475)			
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Issuer FE	Yes	Yes	Yes	Yes	Yes	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes	Yes
Seniority FE	Yes	Yes	Yes	Yes	Yes	Yes
Debt type FE	Yes	Yes	Yes	Yes	Yes	Yes
Embedded option FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	434500	517188	517188	206052	234332	299550
R^2	0.781	0.775	0.775	0.761	0.774	0.770
Adjusted R^2	0.781	0.775	0.775	0.761	0.774	0.770

Standard errors in parentheses, clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Robustness check - matching
The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of matched euro area green and conventional bonds between 2016 and 2023. The regression in Column (1) is performed on a sample of 739 bonds without embedded options. The regression in Columns (2) and (3) are performed on the full sample of 894 bonds interacting the green bond dummy variable with the bid-ask spread and duration of a bond. Column (4) shows the result of a subsample of 324 bonds for which the amount issued of the two bonds of a pair is exactly the same. Column (5) shows the results for a sample of 400 bonds that were matched also by the year of issuance. Column (6) is performed on a sample of bonds where the coupon rate of a green and conventional bond in a pair differs by at most 0.5 p.p.

	(1) Issuer-time fixed effects	(2) Pair-clustered standard errors	(3) Credible bond and UNEP FI	(4) Excl. German issuers	(5) Quarterly retail share
Green	-3.702***	-3.714***	6.860	-2.397**	-3.386***
	(1.341)	(4.353)	(4.367)	(1.069)	(1.094)
External review			-8.298*		
			(4.467)		
UNEP FI			-17.063*		
			(10.081)		
Green × UNEP FI			-4.861***		
			(1.234)		
Retail share					0.929
					(7.479)
Green × Retail share					-2.361*
					(1.206)
Share other EA holders					4.480
					(6.615)
Controls	Yes	Yes	Yes	Yes	Yes
Issuer FE	Issuer-Time FE	Yes	Yes	Yes	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes
Seniority FE	Yes	Yes	Yes	Yes	Yes
Debt type FE	Yes	Yes	Yes	Yes	Yes
Embedded option FE	Yes	Yes	Yes	Yes	Yes
Observations	517254	517254	517254	214406	8743
R^2	0.833	0.775	0.776	0.800	0.768
Adjusted R^2	0.832	0.775	0.776	0.800	0.765

Standard errors in parentheses, clustered at the bond and issuer level unless specified otherwise.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Robustness check - Specification
The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date. Regressions shown in Columns (1) to (3) are performed on a daily panel dataset of a sample of 984 matched euro area green and conventional bonds between 2016 and 2023. In Column (1), the baseline regression specified in Equation 2 is implemented but also issuer-time fixed effects are added. In Column (2), the regression specification is not modified but standard errors are instead clustered at the pair-level. In Column (3), the external review variable indicates if a green bond satisfies all ICMA Green Bond Principles and has also been reviewed by a third party. The UNEP FI variable indicates if a bond was issued by a bank that is part of the United Nations Environment Program Finance Initiative. The regression in Column (4) is the baseline regression in Equation 2 without modification, but performed only on non-German issuers on a sample of 374 bonds. Column (5) shows the results for the full sample, but reduced to quarterly instead of daily frequency.

	(1)		(2)		(3)	
	Retail, no UNEPFI		UNEPFI, no retail		UNEPFI, no retail	
Green	16.788***	(5.667)	-11.592*	(6.085)	-7.422***	(2.235)
Green × Q4 2016			0.000	(.)		
Green × Q1 2017			0.000	(.)		
Green × Q2 2017	0.000	(.)	0.000	(.)		
Green × Q3 2017	1.218	(0.950)	0.000	(.)		
Green × Q4 2017	-2.477	(1.983)	0.000	(.)		
Green × Q1 2018	0.000	(.)	0.000	(.)		
Green × Q2 2018	-25.423***	(2.754)	0.000	(.)		
Green × Q3 2018	-30.053***	(2.572)	0.134	(6.259)		
Green × Q4 2018	-31.052***	(2.341)	4.672	(6.231)		
Green × Q1 2019	-26.949***	(2.928)	15.031	(11.893)		
Green × Q2 2019	-32.958***	(3.785)	25.543	(19.135)		
Green × Q3 2019	-38.280***	(6.251)	3.614	(13.610)		
Green × Q4 2019	-41.251***	(7.681)	6.355	(13.850)		
Green × Q1 2020	-39.756***	(5.254)	13.408	(14.333)		
Green × Q2 2020	-28.134***	(7.092)	21.621	(13.727)		
Green × Q3 2020	-36.432***	(4.967)	13.578*	(7.408)		
Green × Q4 2020	-47.952***	(9.841)	16.831***	(5.520)		
Green × Q1 2021	-46.300***	(7.683)	12.865	(8.187)		
Green × Q2 2021	-30.129**	(10.509)	10.662	(8.942)		
Green × Q3 2021	-25.577**	(10.262)	10.397	(8.321)		
Green × Q4 2021	-17.472**	(7.477)	9.511	(8.811)		
Green × Q1 2022	-19.398**	(7.333)	6.178	(9.865)		
Green × Q2 2022	-12.608	(7.350)	5.398	(8.695)		
Green × Q3 2022	-4.949	(8.294)	5.160	(6.724)		
Green × Q4 2022	-2.186	(8.094)	3.540	(4.838)		
Green × Q1 2023	-15.580	(10.411)	-0.400	(3.412)		
Green × Q2 2023	-12.242	(11.959)	-0.022	(2.597)		
Green × Q3 2023	-8.124	(8.100)	-1.805	(1.173)		
Green × Q4 2023	-15.866**	(7.401)	0.000	(.)		
Controls	Yes		Yes		Yes	
Issuer FE	Yes		Yes		Yes	
Currency FE	Yes		Yes		Yes	
Seniority FE	Yes		Yes		Yes	
Debt type FE	Yes		Yes		Yes	
Embedded option FE	Yes		Yes		Yes	
Observations	22191		61510		61510	
R^2	0.892		0.846		0.800	
Adjusted R^2	0.891		0.846		0.800	

Standard errors in parentheses, clustered at the issuer-bond level.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Robustness check - time dynamics and retail investors
The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date between 2016 and 2023. The regression shown in Column (1) is performed on a subset of 47 bonds that have been predominantly bought by retail investors (at least 50 %) but have not been issued by UNEP FI banks. Results in Column (2) and (3) are for a subset of 123 bonds that have been issued by UNEP FI banks but not bought by retail investors (the average holding share of retail investors is less than 2%). In Columns (1) and (2) the green dummy variable is interacted with a dummy variable for each quarter.

	(1)		(2)	
	All bonds, triple interaction		All bonds, double interaction	
Green	9.985	(8.034)	5.690	(4.658)
Retail share	14.740	(37.730)	5.843**	(2.397)
Green × Retail share	-1.395	(19.488)	-2.892**	(1.382)
Green × Retail share × Oil	-0.100	(0.063)		
Green × Retail share × 3M Euribor yield	1.437**	(0.627)		
Green × Retail share × MSCI Europe	0.077	(0.134)		
Green × Retail share × MSCI rel. porf.	-0.380**	(0.190)		
Green × Retail share × VIX Index	0.000	(0.139)		
Green × Retail share × Google	-0.002	(0.003)		
Green × Oil	0.051	(0.050)	0.014	(0.038)
Green × 3M Euribor yield	-0.132	(0.510)	0.643	(0.586)
Green × MSCI Europe	-0.122	(0.088)	-0.056	(0.047)
Green × MSCI rel. porf.	0.239*	(0.129)	-0.030	(0.094)
Green × VIX Index	-0.185***	(0.066)	-0.148***	(0.055)
Green × Google	0.001	(0.002)	-0.002	(0.001)
Retail share × Oil	0.430***	(0.128)		
Retail share × 3M Euribor yield	7.457***	(1.810)		
Retail share × MSCI Europe	-0.318	(0.242)		
Retail share × MSCI rel. porf.	-1.567***	(0.235)		
Retail share × VIX Index	-0.387	(0.245)		
Retail share × Google	-0.007	(0.005)		
Oil	0.224*	(0.118)	0.367**	(0.144)
3M Euribor yield	2.763	(3.611)	5.727	(4.176)
MSCI Europe	-0.404**	(0.187)	-0.711***	(0.232)
MSCI rel. porf.	-1.939***	(0.318)	-2.408***	(0.474)
VIX Index	1.049***	(0.162)	0.867***	(0.139)
Google	-0.019***	(0.004)	-0.020***	(0.003)
EA share	-1.168	(5.493)	-1.010	(5.571)
Controls	Yes		Yes	
Issuer FE	Yes		Yes	
Currency FE	Yes		Yes	
Seniority FE	Yes		Yes	
Debt type FE	Yes		Yes	
Embedded option FE	Yes		Yes	
Observations	469735		469735	
R^2	0.836		0.810	
Adjusted R^2	0.836		0.810	

Standard errors in parentheses,clustered at the bond and issuer level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 12: Robustness check - Macro-factors and the greenium
The dependent variable in all regressions is the option-adjusted spread (OAS) of a bond on a given date. Regressions are performed on a daily panel dataset of a sample of 800 matched euro area green and conventional bonds between 2016 and 2023. "ESG Equity relative performance" is the difference in return between the MSCI Europe ESG Leader and MSCI Europe Index. "Google" is the measure of search intensity captured by Google trends for the terms "Green bond" and "ESG". "Retail share" indicates the holding share of euro area retail investors, computed as the amount held by retail investors divided by the total outstanding amount of the bond. "EA share" is the total holding share of euro area investors.

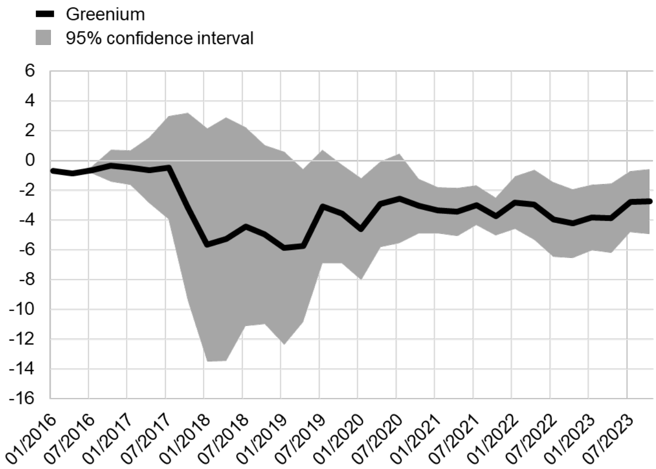

Figure 13: Greenium trend on pairwise regression

The figure shows the constant estimated from a regression of the pair-wise daily difference in the OAS between the green and conventional bond of a pair, for a sample of 447 bond pairs between 2016 and 2023. It also accounts for the pairwise difference of a number of control variables. The control variables are the bid-ask spread, the duration, senior bond dummy, the logarithm of the amount issued and the coupon rate.