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Zagreb International Review of Economics & Business, Vol. 27, No. 2, pp. 7-26, 2024

Faculty of Economics and Business, University of Zagreb and Sciendo. Printed in Croatia.
ISSN 1331-5609; UDC: 33+65
DOI: 10.2478/zireb-2024-0015

Analysis of Green Bond Yields in Different Economic Regimes: High and Low Interest Rates

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Abstract: *In recent years, green bonds have emerged as a significant financial instrument, attracting considerable attention as a means of financing environmentally sustainable projects. This research aims to examine whether there is a statistically significant difference in the returns of green and conventional bonds in international markets under two different stages of the economic cycle, low and high interest rate regimes. The study was conducted based on the bond matching method, where bonds with identical characteristics are considered, except for one, whether or not the bond is green. The results of this study demonstrate the existence of a green premium in both economic regimes. Additionally, an increase in the green premium was identified in the regime of positive interest rates. Considering the observed differences in the green premium across different sectors, it seems that the theory of lower risk of green bonds best explains the reason for the greenium.*

Keywords: Green Bonds; Returns; Premium; Interest Rates

JEL Classification: C58; G15; Q56

Introduction

Financial markets represent the fundamental mechanism through which key investment decisions are made and capital is allocated. In recent years, financial markets have experienced significant volatility, reflecting all the changes in the social and socio-political domains. One of these changes is undoubtedly the growing global awareness of economic challenges and the urgency of reducing climate change. As a

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result, there has been an increase in so-called green bonds in the financial markets, which serve as a powerful financial instrument channeling capital towards environmentally sustainable projects. These financial instruments share many characteristics with conventional bonds. Specifically, green bonds are debt securities issued by government agencies, international institutions, or corporations with the aim of raising capital for projects that contribute to the development of a green, climate-resilient economy with minimal negative impact to environment (Ntsama et al., 2021). There are claims, especially from direct participants in international capital markets, that green bonds offer lower yields compared to comparable conventional bonds. If this is true, it would mean that investors "reward" the green orientation of issuers of such projects by allowing the purchase of these bonds at lower yields, thus lower financing costs. This can be due to various reasons, such as lower perceived risk, investor preference for a green economy, institutional isomorphism, or other motives, some of which will be discussed in the following chapter. The premium in yield at which green bonds trade compared to conventional bond yields is also known as the greenium[1] (derived from green premium) (Larcker and Watts, 2020) and is at the core of this study. Specifically, this study has a dual nature. It aims to determine whether a greenium exists (i.e., a difference in yield between green and comparable conventional bonds) and whether there is a statistically significant difference in the returns of green and conventional bonds in international markets under two different stages of the economic cycle, namely, low and high interest rate regimes.

The research was conducted based on the bond matching method, where bonds with identical characteristics, except for one, whether the bond is green or not, were selected. This method controls for key factors that may affect bond prices (yields), such as the issuer's credit quality, maturity, categories, types of securities, and other characteristics. Subsequently, appropriate panel data models will be used to obtain coefficients for a more detailed analysis of the yields of different bonds in the two economic regimes.

Literature Review

In order to provide a comprehensive analysis of the yield and price differential between green bonds and comparable conventional bonds, this section will cover an analysis of theoretical and empirical studies that can contribute to a better understanding of the issue. Specifically, the theoretical reasons for the potential existence of yield differentials, the so-called greenium, will be analyzed, as well as the reasons why this differential may vary in different economic regimes. The second part of the analysis will focus on the empirical findings of previous studies investigating the yield differentials of green bonds.

Theoretical Reasons for the Greenium

The traditional view of bond yields is that they solely reflect the risk associated with the bond in the overall economic context. In line with this perspective, it is argued that green bonds inherently carry a lower level of risk compared to comparable conventional bonds. Certain risks associated with green bonds, such as achieving environmental benefits and the allocation of finances after bond issuance, are subject to additional monitoring and verification by third parties to ensure their green status (Löffler et al., 2021). On the other hand, conventional bonds may have risks unrelated to green bonds, such as reputation risk due to inadequate environmental practices, future taxation risks due to negative impact on environment (e.g., carbon tax), and others. These potentially increased risks of conventional bonds and potentially lower risks of green bonds due to enhanced oversight can result in yield differentials, i.e., the presence of a greenium.

Contrary to the traditional view, in one study criticizing the traditional Capital Asset Pricing Model (CAPM), Fama and French (2007) explain how investors may have different preferences in the capital market. The authors criticize the traditional model based on two factors: (i) the assumption of complete agreement among investors regarding future payoffs from a particular investment, and (ii) the assumption that all investors base their decisions solely on those predicted future payoffs. Fama and French (2007) argue that these assumptions may be quite unrealistic as investors have varying tastes and preferences that could significantly influence their decisions. The pricing impact of tastes and preferences is similar to the influence of investor disagreement, with one major difference. While investor disagreement about certain market characteristics is essentially short-term and lasts only as long as individual investors realize they are misinformed, the impact of tastes and preferences is long-term and can persist in the capital market, similar to the market for goods, defying economic logic (Fama and French, 2007). The authors cannot assert the magnitude or extent of such influences, but it appears that green bonds can serve as an empirical test of this theory.

A third possible explanation for the existence of greenium comes from organizational studies. Mizruchi and Fein (1999) argue that institutions are entities seeking legitimacy from the community. Institutions gain legitimacy when they adopt practices that are socially and culturally acceptable in the broader society. Therefore, companies and institutional investors become similar in certain actions, adhering to pre-defined institutional norms. Some of these norms in contemporary society undoubtedly include a green orientation and a more comprehensive concern for the environment. These norms can be institutionalized through (i) coercive means, where an authority outside the organization enforces certain actions with the power of sanctions; (ii) imitation, where the organization itself adopts certain actions due to the perception that the rest of the industry or industry leaders have embraced a particular

practice, and (iii) normative means, which arise as a consequence of professionalization in the industry (Powell and DiMaggio, 1991). Given that there is currently no mandate for the purchase or holding of a portion of the portfolio in green bonds, we can only suggest that the latter two forms of institutionalization may be at play. Thus, in a situation where holding green bonds is deemed desirable due to acceptance by the community in which investors operate and to maintain their legitimacy, there is an increase in demand for such bonds, which subsequently leads to higher prices in the market, i.e., lower yields.

Theoretical Reasons for the Greenium in Two Economic Regimes

One of the main objectives of this study is to determine whether there exists a different level of greenium in two economic regimes, namely low and high interest rate regimes. By interest rates, we refer to benchmark interest rates that further determine yields on all bonds within the same economic system. Such an answer would generally provide insights into the potential asymmetry of investors in investing in green bonds with lower yields in different regimes. This goes in line with the work of Alipanah and Kiss (2022) that shows benefits of analyzing returns on international markets accounting for different regimes and ECB policy cycles.

In this regard, we delve into the domain of behavioral finance, which explains investor behavior that is not strictly rational. The pioneers of this theory, Kahneman and Tversky (1979), explain how individuals make decisions to maximize utility functions. This theory suggests that decisions are made to maximize gains and/or minimize losses, rather than considering overall economic wealth. According to the authors, potential losses are valued two or even three times more than potential gains. In financial markets, as Tversky and Kahneman (1992) state in their latter study, the coefficient of loss aversion is 2.25, indicating that investors value losses more than twice as much as potential gains. Numerous authors have investigated this phenomenon in financial markets. For example, Hwang and Satchell (2010) find results indicating that risk aversion is much higher during bull markets than bear markets in financial markets. Fenghua et al. (2014) also discuss the theory of asymmetric risk aversion, concluding that for the same loss (or gain), investor behavior suggests a higher tolerance for risk during periods of losses compared to periods of higher returns when they exhibit greater risk aversion.

In the context of this research, this theory suggests that investors attach greater importance to the difference between yields on green and conventional bonds during periods of negative interest rates compared to periods of positive interest rates.

Empirical Research on the Existence of the Greenium

As the issuance of green bonds has increased, the topic of the greenium has become significant in academic discourse. However, previous empirical studies have not shown consensus regarding the greenium. This partly motivated this study, considering that different results can arise due to research conducted in different time periods and economic regimes.

The first group of studies provides evidence for the existence of the greenium, showing that it is statistically and factually significant. Agliardi and Agliardi (2021) presented evidence of the greenium's existence. The authors also concluded that there is much higher demand for green bonds during primary issuance compared to conventional bonds. The sample in this study includes over 1,000 bonds over a period of nearly four years (from July 2014 to May 2018). The study concluded that the greenium during bond issuance, in the primary market, ranges from 6 to 13 basis points, depending on the risk-free interest rate level (when the risk-free interest rate is lower, close to zero, the greenium is also lower, around 6 basis points). Slightly lower results, depending on the observation period, were obtained in the study by Damico et al. (2023). The authors found that the greenium exists in the market for German government bonds and ranges from 4 to a maximum of 7 basis points. The existence of the greenium was also investigated by Baker et al. (2018) in the American market, considering corporate and municipal bonds. Their result indicates a significant greenium at a level of 26 basis points, which is equivalent to the difference in yield between bonds with a two-notch rating difference.

The second group of studies includes works that found a very moderate greenium or did not find it at all. One such study is based on bond pairing methodology by Zerbib (2019). This study, conducted on a sample of just over 100 bonds issued in multiple currencies, found a very small greenium of only 2 basis points. Similarly, Larcher and Watts (2020) conducted research using the bond pairing methodology and obtained around 600 pairs of green and comparable conventional bonds. Their results indicate that there is no significant difference in yields between these bonds, suggesting that they can be considered perfect substitutes. Kurnoga et al (2022) analyzed ESG indexes and conventional European equity indices, and found no significant performance differences.

However, there are also studies that indicate that the yield on green bonds is actually higher than that of comparable conventional bonds. One such study is by Karpf and Mandel (2017), which was conducted in the U.S. market for municipal bonds. This study concluded that the green nature of the bonds is actually penalized in the market, resulting in lower prices and consequently higher yields for such bonds.

Methodology

In the process of analyzing green and conventional bonds, it is necessary to first find adequate and comparable conventional bonds in order to determine the yield difference that arises solely from one characteristic, which is that the bonds are green, excluding all other potential sources of differences. For this purpose, the bond pairing methodology, previously used in similar studies by Helwege et al. (2014), Zerbib (2019), Larcher and Watts (2020), and others, has been accepted as an appropriate method of analysis in this study. As stated by Zerbib (2019), this is a very useful technique for analyzing the intrinsic value of a financial instrument.

The process of creating the bond pairs involved collecting green bonds (in the study, only bonds certified as green by a third party were used) and pairing each of them with two conventional bonds. In contrast to the study by Helwege et al. (2014), which paired bonds that were closest in terms of maturity, this study took the standpoint that such pairing could lead to bias. Therefore, triplets of bonds were created, consisting of a green bond and two comparable conventional bonds. This approach was accepted but also modified compared to the work of Zerbib (2019).

The process of selecting conventional bonds and assessing their comparability was carried out by ensuring that the conventional bonds were issued by the same issuer as the green bonds, with the same characteristics regarding ratings, bond subordination, bond form, and coupon payment. Since it is almost impossible to find bonds with the exact same maturity as the green bonds, the selection was made in such a way that the two comparable conventional bonds could not have a maturity that was more than 2 years longer or shorter than the maturity of the green bond. Based on the two comparable conventional bonds, the yield of the derived comparable bond is calculated using the formula:

$$y_{i,t}^{CB} = \alpha + \beta * Maturity_{GB} \quad (1)$$

for each bond (i) and for each day in the sample (t). Where α is the intercept and β is the slope of the linear function that passes through the coordinates (Maturity_CB1, Yield_CB1) and (Maturity_CB2, Yield_CB2). With this formula, we obtain the yield of the derived comparable bond where the potential yield bias due to different maturities is controlled[2]. This potential bias will be tested in later iterations. It will be done by including a variable that measures the distance between the selected conventional bonds used to create the derived comparable bond as one of the variables that potentially affects the yield difference. If we have the yield of the green bond y_(i,t)^GB and the yield of the derived comparable bond obtained this way, the yield difference is calculated using the formula:

$$\Delta y_{i,t} = y_{i,t}^{GB} - y_{i,t}^{CB} \quad (2)$$

The second characteristic that potentially couldn't be fully controlled in the model is liquidity. The liquidity of a bond can significantly impact its price and therefore its yield, so it is necessary to control for potential differences in liquidity. This was done based on the issuance value itself during the selection process of comparable bonds, limiting the comparable bonds in a range of a maximum of 4 times the value of the green bond and a minimum of one-fourth of the total amount of the green bond. Some authors use the issuance date as a measure to restrict liquidity differences (e.g. limiting the date of issuance to +/- six years; Zerbib, 2019). However, the author believes that such a range, even wide as six years, is not necessary because the issuance date is often an invisible category for investors or a category that investors do not consider when trading. Nevertheless, the restriction imposed in the selection of conventional bonds may not be sufficient, and there may still be potential residual liquidity effects. Therefore, the first step in assessing the green premium is to remove this influence. This was done by creating a liquidity variable in the following form:

$$\Delta LIQ_{i,t} = LIQ_{i,t}^{GB} - LIQ_{i,t}^{CB} \tag{3}$$

Since measuring the liquidity of bonds directly is challenging, a proxy for liquidity was used, namely the bid-ask spread. This measure has been widely utilized as an indicator for liquidity in previous studies (e.g., Dick-Nielsen et al., 2012; Zerbib, 2019). Similar to the yield measure, for this liquidity measure in conventional bonds (used in the formula 3), derived liquidity was calculated. The liquidity of the derived conventional security is determined as a weighted average of two selected comparable securities, using the following formula:

$$LIQ_{i,t}^{CB} = \frac{d_2}{d_1+d_2} LIQ_{i,t}^{CB_1} + \frac{d_1}{d_1+d_2} LIQ_{i,t}^{CB_2} \tag{4}$$

The liquidity is measured by the difference between the bid and ask yield (bid-ask spread), and d_1 and d_2 are measures of the absolute difference in maturity between the conventional bonds and the green bond, calculated as follows:

$$d_1 = |Maturity\ of\ the\ green\ bond - Maturity\ of\ the\ first\ conventional\ bond|$$

and

$$d_2 = |Maturity\ of\ the\ green\ bond - Maturity\ of\ the\ second\ conventional\ bond|$$

(5a, 5b)

The obtained liquidity difference between the green and derived conventional bonds (Formula 3) was used in a panel fixed effects model, which has the form:

$$\Delta y_{it} = \alpha_i + \beta \Delta LIQ_{i,t} + \mu_{i,t} \tag{6}$$

Fixed effects models were tested to determine their adequacy, but they are also theoretically preferred for at least two reasons. The first reason is that the interest in this study lies in identifying effects specific to each individual bond, independent of time categories and without incorporating information from other securities. Another reason is that this approach helps control for potential endogeneity issues, allowing for unbiased and consistent estimates.

Thus, based on the fixed effects model, estimates of the green premium (greenium) were obtained for each panel, which were further used in the analysis to uncover the sources of this premium and examine potential differences in two economic regimes. This analysis was conducted using an ordinary least squares regression with the following form:

$$\hat{\alpha}_i = \beta_0 + \beta_1 Rating + \beta_2 Subordination + \\ + \beta_3 MaturityType + \beta_4 Distance + \mu_i \tag{7}$$

Where:

- *Rating* represents the bond rating on a scale from 1 to 9, where 1 indicates the lowest rating and 9 the highest rating. The lowest rating in the sample was BBB, while the highest was AAA. Each individual notch is separately noted (e.g., bonds with ratings of BBB, BBB+, A-, A, A+, AA-, AA, AA+, AAA).
- *Subordination* (level) denotes the level of bond subordination, where lower values indicate lower positions in the subordination hierarchy (such as Tier 2 and Subordinated bonds) with lower investor security, while higher values indicate higher levels (such as Senior and Secured bonds) with higher investor security.
- *MaturityType* indicates whether the bond has a call option or a fixed maturity date.
- *Distance* refers to the logarithmic difference in the number of days between the maturity of the green bond and the closest comparable conventional bond[3].

This study will focus on euro-denominated bonds from the government, supranational, and corporate sectors. The reason for using only euro-denominated bonds lies in the fact that central banks worldwide have started implementing restrictive monetary policies at different times. Isolating a single system can contribute to better understanding of the issues and more precise analysis. The bond selection was based on initial gathering of a list and basic characteristics of green and comparable conventional bonds from the ICE Index platform (previously Merrill Lynch indices), followed by retrieving yield and price data from the Bloomberg platform.

Results of the Analysis

In this section, empirical findings regarding the yield differences between green and conventional bonds in two economic regimes will be presented. The results are divided into two subsections. The first subsection provides a basic description of the data and a preliminary regression analysis, which serves as a filter to determine the consistency of the results. The second part analyzes the results obtained in different regimes, both in summary and in individual subcategories. It also presents a regression analysis aimed at identifying the sources of potential green premium. Overall, these findings contribute to our understanding of the financial dynamics and market performance of green bonds compared to their conventional counterparts.

Data description and preliminary analysis

The strict selection of green and comparable bonds used in this study, as described in the previous chapter (which includes all characteristics of comparable bonds, such as issuance amount, maturity date, bond form, subordination, etc.), has resulted in a significant reduction of the initially collected sample. Initially, there were nearly 500 euro-denominated bonds contained in the green bond index, but through filtering, this number was reduced to 78. However, considering that the data indicates the total current bond market to be estimated at around 900 billion euros, and the total issuance amount of these 78 bonds used in the analysis exceeds 380 billion euros, it can be concluded that this is a representative sample, comprising over 42% of all euro-denominated bonds. The data was collected from December 2021 to May 2023.

For the analysis of yield differences in two economic regimes, the entire dataset, which consisted of 28,548 daily data points, was divided into two (main) segments. The first segment was defined from the initial date to July 1, 2022. These subsamples excluded the months of July, August, and September, as the European Central Bank (ECB) began increasing the reference interest rate at the end of July 2022, when the deposit facility rate was increased from -0.5% to 0%, and during September increased to positive 0.75%. This period of exclusion can be interpreted as a period of investor adjustment to the new environment. The second segment covers the period from the beginning of October 2022 to the end of May 2023. In this process, the author was primarily constrained by the period after the increase in reference interest rates, so the selection of the first and initial date in the negative interest rate period was conditioned by the length of the positive interest rate regime period (aiming for a symmetrical sample - the same time period in both regimes).

In the figures below, the basic characteristics of (green) bonds in the sample are presented. It can be seen in the Figure 1 that the largest number of bonds in the sample have been issued with a face value of up to one billion. Additionally, as Figure 2 sug-

gests, all bonds have an investment grade rating, although the majority are grouped in the lower investment grade (BBB, BBB+, and A-) and prime rating (AAA). The sample consists of 37 corporate bonds, 24 supranational bonds, and 17 government bonds (depicted in Figure 3). The distribution of these bonds by years to maturity and by the value of the issuance can be seen in Figure 4. From the Figure 4, it is evident that government bonds have a slightly shorter maturity period than others, with their maturity occurring within the next five years, while corporate bonds have both the longest maturity period and the highest face value.

Figure 1: Face value distribution

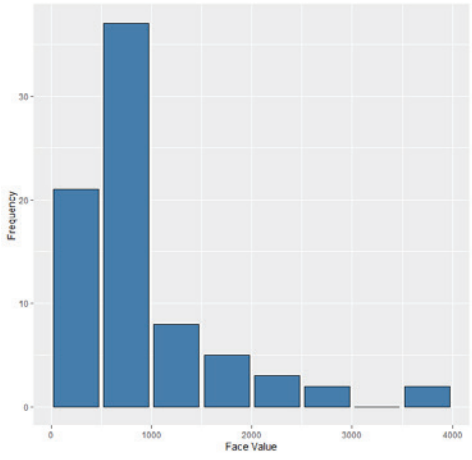


Figure 2: Distribution of bonds by rating

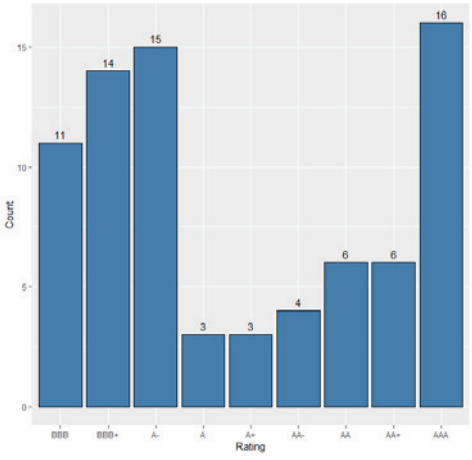


Figure 3: Distribution of bonds by sector

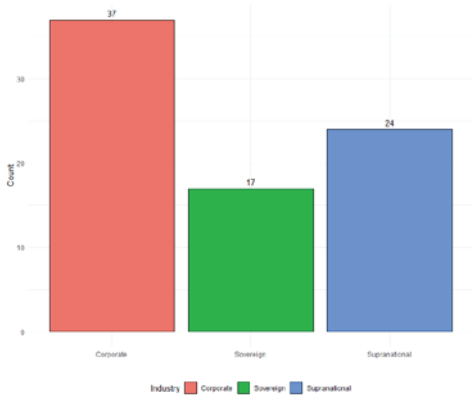
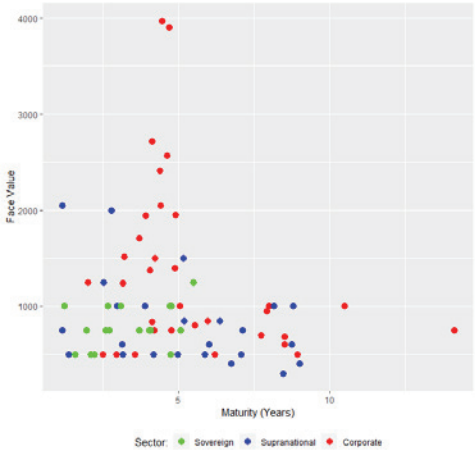


Figure 4: Maturity of bonds vs face value



The following graphs depict the basic characteristics of yield data. Figure 5 shows the movement of average yields for green and conventional bonds. From Figure 5, it can be observed that the average yields increased during this period, reaching a stable level slightly above 3% in the second regime. Additionally, it can be concluded that the green line representing average yields of green bonds is generally below the red line representing conventional bonds, indicating that green bonds have slightly lower yields. This is evident from Figure 6, which shows the yield spread between the two. Moreover, Figure 6 suggests that this spread differs between the two regimes, with the average spread in the second regime being below the average level in the first period. Testing this conclusion will be conducted in subsequent sections.

Figure 5: Average Yields

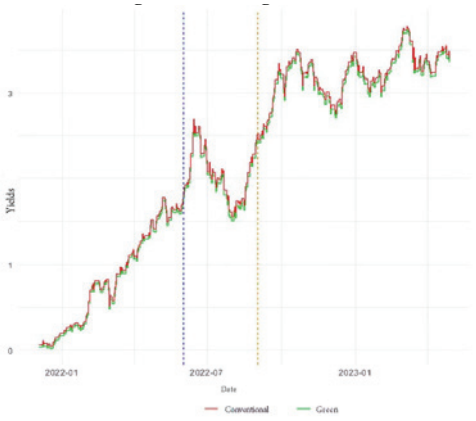
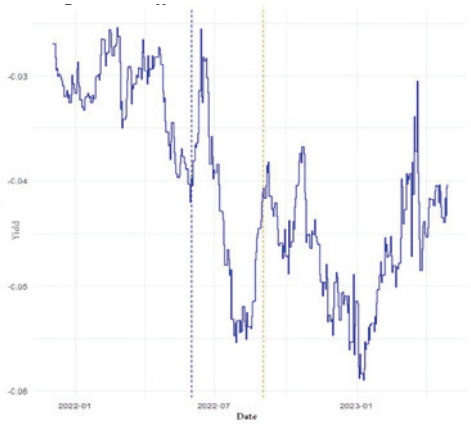


Figure 6: Difference in Yield Movement



In the methodology section, it was mentioned that liquidity was controlled for using certain conditional variables such as issuance amount. However, it is known in the literature that this might not be sufficient to control for liquidity differences. Therefore, the yields were evaluated based on formula (6) for each individual time period and the overall period. This model examines whether there is any level of residual liquidity that was not controlled for or accounted for in the previous selection of comparable bonds. The results are presented in Table 1 below. As stated, this model was assessed using a fixed effects panel model[4]. As seen in the table, in none of the samples or subsamples is the liquidity variable statistically significant. This indicates that the previous restrictions for potential liquidity differences have been effective, and liquidity does not have any statistically significant impact on yield difference. Furthermore, since all other bond characteristics were controlled for through the selection of comparable bonds, the yield difference is solely attributable to the bond being green and certified as such by a third party.

Table 1; Examination of the Impact of Liquidity on Yield Difference

		Overall Sample	Low-Interest Rate Regime	High-Interest Rate Regime
Constant	**Coefficient**	**-0.0412*****	**-0.0328*****	**-0.0456*****
	R.S.E.	0.0015	0.0005	0.0025
Liquidity	**Coefficient**	**-0.1100**	**-0.3793**	**0.2764**
	R.S.E.	0.3895	0.2342	0.4986
R squared		**0.0003**	**0.0050**	**0.0030**
F statistics		**0.7785**	**0.1094**	**0.5810**
Number of Observations		28,548	11,700	11,700
Number of Panels		78	78	78

Note: R.S.E. refers to robust standard error; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Analysis of the Greenium

As determined in the previous part of the analysis, there is no residual liquidity that would impact the yield differences between green and conventional bonds. Therefore, the differences in yields can be analyzed. The table below presents the differences between green bonds and comparable conventional bonds, along with confidence intervals. Additionally, the table displays the differences for each sector, specifically analyzing the premiums on green bonds in the government, supranational, and corporate sectors. Considering the overall sample, during the period of negative interest rates, the premium on green bonds amounted to 3.2 basis points, while in the period of positive interest rates, it was nearly 1.5 basis points higher at 4.7 basis points. However, when examining individual sectors, this difference did not occur symmetrically across all sectors. In the government and supranational sectors, the premiums on green bonds remained almost identical. However, in the corporate sector, the premiums on green bonds significantly increased, ranging from nearly 6 basis points in the period of low interest rates to almost 12 basis points in the period of high interest rates.

Table 2: Analysis of the greenium in different sectors

		Negative IR* Regime		Positive IR Regime	
Overall Sample	**Mean:**	**-0.0319**		**-0.0469**	
	95% Conf. Interval:	-0.0333	-0.0305	-0.0492	-0.0447
Government	**Mean:**	**-0.0340**		**-0.0339**	
	95% Conf. Interval:	-0.0360	-0.0319	-0.0366	-0.0312
Supranational	**Mean:**	**-0.0073**		**-0.0075**	
	95% Conf. Interval:	-0.0093	-0.0052	-0.0096	-0.0054
Corporate	**Mean:**	**-0.0573**		**-0.1172**	
	95% Conf. Interval:	-0.0607	-0.0539	-0.1238	-0.1105

Note: IR refers to interest rates

In addition to analyzing the green premium in different sectors, the sources of such premium were also examined using formula (7). An ordinary least squares regression analysis was conducted to determine whether variables such as maturity type, rating, subordination level, and the logarithmic difference in days between the maturity of the green bond and the nearest comparable conventional bond (distance variable) have any impact on the green premium, and whether this impact differs in different interest rate regimes. Consistent with our expectations and confirming the validity of the process of selecting comparable bonds, the distance variable does not have a statistically significant impact on the green premium. The call option variable (maturity type) has a statistically significant impact on the green premium only in the positive interest rate regime, while the subordination variable has a positive impact on the green premium in both regimes, with the impact being more than double in the positive interest rate regime.

Table 3: Factors contributing to the greenium

	Negative IR Regime	**Positive IR Regime**
Maturity Type	**-0.0246**	**-0.0657***
	0.0188	0.0349
Subordination Level	**0.0314****	**0.0697*****
	0.0130	0.0037
Rating	**0.0015**	**0.0011**
	0.0028	0.0037
Distance	**-0.0011**	**-0.0019**
	0.0081	0.0149
Constant	**-0.1950*****	**-0.3656*****
	0.0684	0.1210
R squared	0.1267	0.2449
F statistics	3.78	9.91
Number of Observations	78	78

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Conclusion and Discussions

This study investigated the existence of a greenium, which represents the difference in yields between green bonds and comparable conventional bonds. Findings from this study provide insights into the dynamics of the green bond market and shed light on the factors that contribute to the greenium, in two economic regimes.

Study confirms the presence of a greenium in the bond market, indicating that investors are willing to accept lower yields for green bonds compared to conventional bonds. It is confirmed for both economic regimes, regime of low and high interest rates. This suggests that investors reward the green orientation of issuers by investing

in environmentally sustainable projects at lower yield (higher price), even though it doesn't contribute to their financial return. Thus, these results suggest that investors, indeed, may have intrinsic tastes and preferences as formulated by Fama and French (2007), that extends beyond traditional financial metrics. According to their findings, investors can value certain non-financial attributes of assets, that could lead to persistent market behaviour. The presence of greenium in both economic regimes found in this paper suggests that these tastes and preferences are not short-term anomalies, but have lasting effects (Fama and French, 2007).

The greenium varied in different economic regimes, with a slightly higher premium observed during periods of positive interest rates. This difference can be attributed to the risk and loss aversion of investors, formulated by Kahneman and Tversky (1979), as investors attach greater importance to yields during periods of negative interest rates, resulting it their lower willingness to forgo some amount of their wealth towards the contribution to environmentally sustainable projects. Coincidentally, for the corporate sector, the difference is roughly times 2, which aligns with the findings of Tversky and Kahneman (1992).

Moreover, paper analyzed the greenium across different sectors and found variations in the premium. In the government and supranational sectors, the greenium remained relatively stable, while in the corporate sector, the premium on green bonds significantly increased. Considering that the green premiums differ across sectors and are influenced by bond subordination, it can be interpreted that the theory of inherent lower risk in green bonds, as noted by Löffler et al., (2021) best explains this phenomenon. Having in mind that the results suggest that the greenium is higher at lower subordination levels, it is possible that greenness of the bond is serving as an offset to this risk (due to lower subordination levels), due to additional procedures related to monitoring and certification associated with it (Loffler et al, 2021).

Additional contribution of this study is developing more formal way of testing biasness of author related to the choice of conventional bonds. In this paper, the variable "distance" was used to assess whether difference in maturities of the used conventional bonds significantly contribute to greenium. The results further attest to the robustness of the model used.

In conclusion, this study highlights the existence of a greenium in the bond market, indicating investor preference for green bonds and potential risk aversion. The variations in the greenium across economic regimes and sectors provide further evidence of the complex dynamics underlying the pricing of green bonds. It also suggests about robustness of the market for the green bonds, driven by the intrinsic value of the bonds – lower risk, but also investors preferences. These findings contribute to a better understanding of the financial implications of environmentally sustainable investments and have implications for investors, issuers, and policymakers in promoting sustainable finance.

The results suggest lasting effect of investors preferences towards green bonds, and that investors have long-term commitment towards environmentally sustainable instruments and promotion of sustainable finance. Investors can use green bonds to diversify their portfolios, having in mind that they are seen as less risky options than their conventional counterparts. Such bonds with intrinsically lower risk provide alternative investment option, that especially during the periods of economic downturn, allow investors to balance returns and their social and environmental impact, while at the same time enhancing resilience of their portfolios. Investing in green bonds is a part of a growing trend of responsible investing, appealing to those who(se clients) prioritize ethical consideration alongside financial returns. Such alignment could enhance reputation and social acceptance of investors, and foster trust and loyalty among all their clients and stakeholders that value sustainability.

For issuers, green bonds have the prime advantage of lower yields, allowing them to access the capital and lower cost. This cost advantage is significant, but it can also enhance the reputation and market positioning of the issuer. By working on their compliance and regulatory standards necessary for issuing green bonds, issuers could attract a broad base of environmentally conscious investors. Thus, issuers could acquire funds for green projects at lower costs, but at the same time, enhance their reputation and market positioning.

Policymakers could play crucial role in developing better environment for responsible investing. They could provide further incentives for the issuance of green bonds, by developing regulatory framework that would encourage sustainable finance. Furthermore, standardized frameworks for monitoring and certification processes are required in different regions/countries and sectors in order to meet the requirements for comparability of the international investors. This will also ensure comparability and transparency of green bonds, but also reduce the risk of greenwashing and promoting genuine efforts and environmental benefits of the green financing.

It is important to note that this study has certain limitations. The analysis focused on euro-denominated bonds and a specific time period, which may limit the generalizability of the findings. Additionally, other factors not explored in this study, such as overall market liquidity (and not just difference in liquidity between green and conventional bonds) and investor demand dynamics, could also influence the greenium. Further research is warranted to explore these aspects and provide a more comprehensive understanding of the pricing dynamics of green bonds. Also, with the growth of the market and diffusion of green financing across countries, researchers might be in a position to assess the greenium across different countries. Namely, this study was constrained with relatively small sample size of bonds from some countries, which could not provide sufficiently robust results on greenium and differences in greenium across countries.

Declarations

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest/Competing interests
There is no conflict of interest/Competing interests

Availability of data and material
The data that support the findings of this study are available through Bloomberg Terminal..

Code Availability
The computer program results are shared through the tables in the manuscript and/or explained in the text.

Authors' Contributions
Not applicable.

Appendix I Bonds used in the study

Sovereign bonds							
ISIN Green Bond	**ISIN CB 1**	**ISIN CB 2**	**Issuer**	**Country of origin**	**Ticker**	**Maturity Date**	**Rating**
IT0001086567	IT0005090318	IT0005433690	Italy	Italy	BTPS	11/1/2026	BBB2
IT0005127086	IT0005424251	IT0004513641	Italy	Italy	BTPS	12/1/2025	BBB2
IT0005170839	IT0005282527	IT0005323032	Italy	Italy	BTPS	6/1/2026	BBB2
IT0005210650	IT0005386245	IT0004889033	Italy	Italy	BTPS	12/1/2026	BBB2
IT0005274805	IT0001174611	IT0005445306	Italy	Italy	BTPS	8/1/2027	BBB2
IT0005345183	IT0005454050	IT0005327306	Italy	Italy	BTPS	11/15/2025	BBB2
DE0001030708	DE0001102564	DE0001102473	Germany	Germany	DBR	8/15/2030	AAA
DE0001102408	DE0001102374	DE0001102523	Germany	Germany	DBR	8/15/2026	AAA
DE0001102416	DE0001135085	DE0001102382	Germany	Germany	DBR	2/15/2027	AAA
DE0001102424	DE0001102440	DE0001102457	Germany	Germany	DBR	8/15/2027	AAA
FR0013250560	FR0013341682	FR0000571218	France	France	FRTR	5/25/2027	AA2
FR0014003513	FR0011317783	FR0012517027	France	France	FRTR	2/25/2027	AA2
IE00BFZRQ242	IE00BKFVC899	IE00BMQ5JL65	Ireland	Ireland	IRISH	3/18/2031	AA3
DE0001141844	DE0001141802	DE0001141810	Germany	Germany	OBL	10/9/2026	AAA
ES00000128H5	ES00000122E5	ES0000012A89	Spain	Spain	SPGB	10/31/2026	A3
ES00000128P8	ES0000012B88	ES00000124C5	Spain	Spain	SPGB	4/30/2027	A3
ES0000012J15	ES0000012I08	ES0000012B39	Spain	Spain	SPGB	1/31/2027	A3

Quasi and supranational bonds							
ISIN Green Bond	**ISIN CB 1**	**ISIN CB 2**	**Issuer**	**Country of origin**	**Ticker**	**Maturity Date**	**Rating**
XS1766612672	XS1209947271	XS1346201616	Poland	Poland	POLAND	8/7/2026	A3
FR0013296373	XS0686487421	XS0936339208	Agence Francaise de Dev.	France	AGFRNC	11/15/2023	AA2
FR0013365376	XS1072438366	FR0014000AU2	Agence Francaise de Dev.	France	AGFRNC	10/31/2025	AA2
FR0013483526	FR0013190188	FR0013220902	Agence Francaise de Dev.	France	AGFRNC	3/25/2025	AA2
XS2068071641	XS2110875957	XS2353057123	Asian Development Bank	International	ASIA	10/24/2029	AAA
DE000A14JZS6	DE000A14JZL1	DE000A14JZP2	Baden-Württemberg	Germany	BADWUR	3/7/2031	AA1
XS1280834992	XS1489409679	XS2120068403	EIB	International	EIB	11/15/2023	AAA
XS2314675997	XS1503043694	XS0960306578	EIB	International	EIB	11/15/2030	AAA
XS2419364653	XS1394055872	XS2154339860	EIB	International	EIB	11/15/2027	AAA
DE000A1RQD43	DE000A1RQD01	DE000A1RQD92	Hessen, Land	Germany	HESSEN	6/18/2031	AA1
XS1912495691	XS2102988354	XS2160861808	IBRD	International	IBRD	11/22/2027	AAA
XS1979491559	XS2173111282	XS2412060092	Instituto de Crédito Oficial	Spain	ICO	1/31/2024	BBB1
XS1612940558	DE000A2GSNW0	DE000A2LQH10	KFW	Germany	KFW	6/30/2025	AAA
XS2209794408	DE000A2GSFA2	DE000A289F29	KFW	Germany	KFW	9/15/2028	AAA
XS2331327564	DE000A2GSNR0	DE000A2LQSH4	KFW	Germany	KFW	6/15/2029	AAA
XS2388457264	DE000A3E5LU1	DE000A2LQSN2	KFW	Germany	KFW	9/15/2031	AAA
XS1692485912	XS1548533329	XS2333658073	Municipality Finance PLC	Finland	KUNTA	9/7/2027	AA1
ES00001010G6	ES0000101909	ES0000101966	Com. Autónoma Madrid	Spain	MADRID	7/30/2028	A3
XS1284550941	XS1626191107	XS2079798562	Waterschapsbank N.V.	Netherlands	NEDWBK	9/3/2025	AAA
DE000NWB0AC0	DE000NWB17G1	DE000NWB0634	NRW.BANK	Germany	NRWBK	11/10/2025	AA1
DE000NWB0AD8	DE000NWB0584	DE000NWB17M9	NRW.BANK	Germany	NRWBK	11/17/2026	AA1
DE000NWB0AH9	DE000NWB18D6	DE000NWB0AP2	NRW.BANK	Germany	NRWBK	10/15/2029	AA1
XS2359292955	XS2405489092	XS1192872866	Land. Rentenbank	Germany	RENTEN	6/30/2031	AAA
XS1938381628	XS0985666436	XS1186684137	SNCF Réseau S.A.	France	RESFER	1/22/2029	AA2

Corporate bonds							
ISIN Green Bond	**ISIN CB 1**	**ISIN CB 2**	**Issuer**	**Country of origin**	**Ticker**	**Maturity Date**	**Rating**
XS1808739459	XS0937858271	XS1218821756	ABN AMRO Bank	Netherlands	ABNANV	4/22/2025	A1
FR0013385515	FR0011559145	FR0011659366	Credit Agricole	France	ACAFP	12/5/2023	AA3
XS2067135421	XS1538284230	XS1790990474	Credit Agricole	International	ACAFP	10/21/2025	A2
DE000A3E5FR9	DE000A28VQD2	DE000A3MP4V7	Vanovia	Germany	ANNGR	3/24/2031	BBB1
XS1820037270	XS1956973967	XS2101349723	BBVA SA	Spain	BBVASM	5/14/2025	BBB1
FR00140003P3	FR0013412947	XS1856834608	Crédit Mutuel SA	France	BFCM	10/8/2027	AA3

Corporate bonds							
ISIN Green Bond	**ISIN CB 1**	**ISIN CB 2**	**Issuer**	**Country of origin**	**Ticker**	**Maturity Date**	**Rating**
FR0013405537	XS1547407830	XS1614416193	BNP Paribas S.A.	France	BNP	8/28/2024	A3
XS1808338542	XS1793252419	XS1823532640	BNP Paribas	France	BNP	4/17/2024	A3
FR0013465358	FR0013398070	FR0013434776	BNP Paribas	France	BNP	6/4/2025	A3
FR00140005J1	FR0014002X43	FR0013508710	BNP Paribas	France	BNP	10/14/2026	A3
FR0014006NI7	FR0013484458	FR0014001JT3	BNP Paribas	France	BNP	5/30/2027	A3
FR0013464930	FR0013204476	FR0013476199	BPCE S.A.	France	BPCEGP	12/4/2024	A1
BE6328785207	BE6317283610	BE6324012978	Belfius Bank S.A.	Belgium	CCBGBB	6/8/2027	BBB1
FR0014000PF1	FR0013286788	FR0013310455	VINCI S.A.	France	DGFP	11/27/2028	A3
XS1550149204	XS0192503695	XS1176079843	ENEL Finance International N.V.	International	ENELIM	9/16/2024	BBB1
FR0013245867	FR0013517190	FR0013344686	Engie S.A.	France	ENGIFP	3/27/2028	BBB1
FR0013428489	FR0012602761	FR0013444775	Engie S.A.	France	ENGIFP	6/21/2027	BBB1
FR0014005ZQ6	FR0012602779	FR0013284270	Engie S.A.	France	ENGIFP	10/26/2036	BBB1
XS2047500769	XS2103015009	XS1595704872	E.ON SE	Germany	EOANGR	8/28/2024	BBB1
XS2103014291	XS2069380991	XS2288948859	E.ON SE	Germany	EOANGR	9/29/2027	BBB1
XS2177580508	XS2077546682	XS2103014457	E.ON SE	Germany	EOANGR	8/20/2031	BBB1
XS2009861480	XS1428782160	XS1560853670	ESB Finance DAC	Ireland	ESBIRE	6/11/2030	A3
FR0013384567	FR0013447604	FR0014001IO6	La Poste	France	FRPTT	11/30/2028	A1
XS2350756446	XS2176621170	XS2407529309	ING Groep N.V.	Netherlands	INTNED	6/9/2027	BBB1
XS1979446843	XS2022425297	XS2089368596	Banca Intesa Sanpaolo	Italy	ISPIM	4/10/2024	BBB2
XS2317069685	IT0001200390	XS1785340172	Banca Intesa Sanpaolo	Italy	ISPIM	3/16/2028	BBB2
DE000A289QR9	DE000A2YNZX6	DE000A289XG8	Mercedes-Benz Group AG	Germany	MBGGR	9/10/2030	A3
DE000A3H3JM4	DE000A2YNZY4	DE000A2YPFU9	Mercedes-Benz Group AG	Germany	MBGGR	3/11/2033	A3
XS1691909920	XS2004880832	XS2049630887	Mizuho Financial Group Inc.	Japan	MIZUHO	10/16/2024	A2
XS2003499386	XS1189263400	XS2171874519	Nordea Bank Abp	Finland	NDASS	5/28/2026	AA3
XS2381853279	XS2231259305	XS2289408440	National Grid PLC	UK	NGGLN	9/1/2028	BBB2
XS2055627538	XS2106056653	XS2381599898	Raiffeisen Bank International AG	Austria	RBIAV	9/25/2026	A2
XS2194370727	XS2113889351	XS2298304499	Banco Santander S.A.	Spain	SANTAN	6/23/2027	A3
XS1957442541	XS2051660335	XS2300208928	Snam S.p.A.	Italy	SRGIM	8/28/2025	BBB1
XS1980270810	XS1652866002	XS2033351995	Terna Rete Elettrica Nazionale S.p.A.	Italy	TRNIM	4/10/2026	BBB2
XS1218319702	XS1523192588	XS1376614118	Unibail-Rodamco-Westfield SE	France	ULFP	3/14/2025	BBB1
XS2002017361	XS1372839214	XS1652855815	Vodafone Group PLC	UK	VOD	11/24/2026	BBB2

NOTES

[1] As mentioned, the "greenium" refers to the difference in yield between green bonds and comparable conventional bonds. Typically, the yield on green bonds is lower than that of comparable conventional bonds, resulting in a negative greenium. However, for the sake of consistency with other literature, in this paper, we will continue to use the terms "green premium" or "greenium" to refer to this concept, without specifically mentioning the negative value.

[2] Essentially, we approximate the yield curve on a small segment using a straight line. If the difference is minimal, the potential bias would be insignificant. However, when there is a substantial difference in maturity, resulting in a larger distance between the conventional and green bond, the potential bias may be more pronounced. In the subsequent sections, it will be explained how this is tested to identify any potential biases.

[3] This variable is included to test the model of selecting comparable bonds. It is evident that if there is a large or significant difference between the maturity dates of the comparable and green bonds, it increases the potential for bias. This potential bias is higher when the yield curve is more convex and when the maturity difference is greater. Through analysis, it has been concluded that instead of considering the sum of differences between each comparable bond and the green bond, only the difference of the closest bond should be taken into account. This approach is stricter but more accurate in nature. Further details will be provided in the Results section.

[4] The fixed effects model was tested using the F-statistic as well as the Hausman test. The tests suggest that the fixed effects model can be used. Specifically, the F-statistic clearly rejects the null hypothesis that the fixed effects are equal to zero. On the other hand, the Hausman test suggests that random effects are valid and desirable. However, as mentioned in the methodology section and in line with suggestions from the literature (e.g., Baltagi, 2021; Greene, 2002), it is possible to use the fixed effects model if there is an additional reason to do so. Furthermore, the model was tested with multiple diagnostic tests, which indicate heteroscedasticity and serial correlation. To address these issues, robust standard errors were used.

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