“Uncovering the greenium: Investigating the yield spread between green and conventional bonds”

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UNCOVERING THE GREENIUM: INVESTIGATING THE YIELD SPREAD BETWEEN GREEN AND CONVENTIONAL BONDS

Abstract

Green bonds are an increasingly used instrument to catalyze cash flows towards a low-carbon economy. Nonetheless, the existence of an actual price advantage is still uncertain. This research paper aims to assess whether there is a green bond premium ("greenium") for green bonds relative to conventional bonds with similar characteristics, and how liquidity may affect the determination of a price advantage. It analyzes the yield differentials between green and conventional bonds using three different methods. First, a Nelson-Siegel-Svensson method is executed, estimating the premium both as the yield spreads and as the differentials in Z-spreads. Using a matching method and creating a sample of green and synthetic conventional bonds, the second methodology consists in calculating the distances between each categories' yield for the same duration. Finally, a fixed-effect regression is performed to better control the liquidity bias. In the first case, a positive premium emerges when analyzing the yield spreads (+37.89 basis points) and the Z-spreads (+10.62 basis points). The second method mitigates the liquidity risk by creating a sample of synthetic bonds and reveals a yield spread of –15.89 basis points. Lastly, the regression method shows a negative greenium equal to –17.1487 basis points. Thus, a greenium emerges from all the three different methods, but its nature, sign, and real determinants are still uncertain. It is, therefore, not possible to conclude a definite price advantage for issuers of green bonds.

Keywords green bonds, yield spread, greenium, liquidity, matching, duration, regression

JEL Classification G11, G12, Q56

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INTRODUCTION

The green bond premium, also called greenium, is the pricing advantage that issuers receive when placing green bonds compared to a conventional bond issue. A greenium may increase the attractiveness of such instruments, overcoming the perception that they are only a preferred tool by a niche of investors and thus being crucial for the realization of the market. Excess demand, high transaction costs, and lack of standardization in labeling criteria are some of the elements that can affect green bond yields: through the analysis of these components and the study of the sector liquidity, the paper explores the measurement of the green bond premium and provides a comprehensive picture of its potential determinants.

The central scientific issue addressed in this study is the empirical validation of the existence of the green bond premium. Specifically, the study aims to determine whether green bonds actually have a yield advantage over conventional bonds and, if so, to clarify the factors underlying this phenomenon. This study is particularly relevant given the growing interest in sustainability issues among investors, issuers, and policymakers, and the role of green bonds as a source of capital market financing.

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To find the best methodology, it was decided to proceed along three different paths, which will then be evaluated and compared: the development of a Nelson-Siegel Svensson (NSS) curve, the calculation of the distances between the green and synthetic conventional bonds' yield curves, and the analysis of the unobserved effect of a fixed-effects regression model. The research dataset includes green bonds and their conventional counterparts, specifically selected to ensure comparability by controlling for issuer, rating, maturity, and coupon type. A set of synthetic conventional bonds was created to mitigate discrepancies and allow a more precise analysis of the impact of liquidity on the green bond premium.

1. LITERATURE REVIEW

The phenomenon of green bonds, albeit considerably expanded, is still too recent to draw appropriate conclusions about the existence of the green bond premium. However, the literature is increasingly focusing on an in-depth study of the dynamics involved in the greenium, and significant results are emerging.

The analysis conducted by Zerbib is one of the most accredited works on the green bond premium investigation (Zerbib, 2019). Zerbib studied the difference in liquidity between green and conventional bonds as an independent variable to explain the yield spread. The study proceeds through a matching method and controls of the residual difference in liquidity between green and conventional bonds, measured through the calculation of the bid-ask spread differential. Zerbib estimates the greenium through a regression model with fixed effects. What emerges is a small but significant negative premium of –2 basis points (b.p.).

The effects of liquidity on the yield differential are also studied by Wundalari et al. (2018), who show that the green bond yield spread is lower than the grey one for values from 5 to 30 b.p. The authors find that liquidity has a significant impact on green bond price and, contrary to their initial expectations, green bonds turn out to be more liquid than their conventional counterparts.

The existence of a greenium may be determined by factors intrinsic to the green bond market, which affect its attractiveness and, hence, its price. The investigation of these determinants is therefore relevant to understand whether the greenium is to be considered as systematic. That is the case of the analysis conducted by Ehlers and Packer (2018). The observed negative greenium is consistent with the excess demand in the green market and supports the hypothesis that investors may opt for holding green bonds in their portfolio to exert influence on the price. Excess of demand is also examined by Preclaw and Bakshi (2015), who find a negative premium of –17 b.p. calculated on the OAS spread of corporate green bonds. According to the study, investors exhibit a willingness to pay a yield premium, at least in the secondary market, driven by an excess of demand for environmentally sustainable funds.

The rising awareness of sustainability-related issues increases the base of investors with environmental preferences. Several studies show that investors are willing to sacrifice part of the gains from the investment to meet their preferences by holding a green bond. Among others, Baker et al. (2018) investigate this phenomenon, observing the yield structure in relation to bond ratings (Strassberger, 2012). On a sample of US corporate and municipal bonds, the authors note that green bonds are priced as if they were in a higher "half notch" rating category and have lower yields between –5 b.p. and –7 b.p.

Different findings are performed by Karpf and Mandel (2018), whose empirical evidence records a positive premium of +7.8 b.p. The study aims to separate the impact on the yield produced by the observable characteristics of the issuer and market from that one produced by the green bond itself. For this reason, the authors perform an Oaxaca-Blinder decomposition (Oaxaca, 1973; Blinder, 1973) of the yield differential between green and conventional bonds. Karpf and Mandel (2018) report a change in the nature of the premium from positive to negative in 2015 onwards, attributable to the improvement in credit quality that green bonds experienced in recent years.

An analysis of the US municipal bond market is also conducted by Partridge and Medda (2018), both of which show a lower yield for green bonds. The first research is based on the examination of 133 green bonds and a sample of conventional bonds from issuers with a green profile; on average, each green bond is paired with 14 grey bonds, and the results show a negative greenium of –1.1 b.p., even though about 37% of the green issues have a higher yield than the conventional bond interpolation curve. Partridge and Medda, on the other hand, analyze the primary and secondary markets, noting an even more pronounced premium of around –5 b.p. for the latter.

Also, the lack of standardization may affect the green bond yield, as issuers could choose a different issuance scheme. In this sense, Katori (2018) compares the utilization status and the financial product characteristics of each of the three green bond issuing schemes, Climate Bonds Standard, Green Bond Principles, and Green Bond Rating. Katori (2018) performs a regression analysis to find out the impact on the spread of the following determinants: compliance with the Green Bond Principles, consistency with the Climate Bonds Standard, green bond rating, and the duration of the bond. The study reveals a negative premium affected by the three categories with different intensities.

Finally, the Climate Bonds Initiative (CBI) examines the performance of 14 green bonds, observing how many and to what extent they are positioned above the yield curve: the results show a very heterogeneous distribution (Climate Bonds Initiative, 2017, 2018, 2019). CBI, acknowledging the limitations of its sample, deduces that green and grey bonds do not show different typical behaviors and undertakes to monitor activities to obtain more comprehensive results.

There appears to be no consensus in the literature on the actual amount of the green bond premium and no firm positions on its effective existence. Liquidity could play a pivotal role in establishing a green bond premium, with its dynamics influenced by various factors, including excess demand, credit quality, and the absence of market standardization.

Within the array of methodologies employed to assess the greenium, this study aims to determine whether a premium exists and estimate its magnitude, particularly focusing on the role of liquidity. To achieve this, the analysis applies three distinct methods, each adept at controlling liquidity dispersion in different ways, while also delving into their limitations and potential insights.

2. METHODS AND ANALYSIS

The green premium has been estimated through a comparison between the yields of conventional (grey) and green bonds with similar characteristics. Three different methodologies have been valued and compared, to compare grey and green bonds, being equal all the conditions, as listed below:

- **Nielson-Siegel-Svensson method:** evaluation of the greenium through a Nielson-Siegel-Svensson curve (Nelson and Siegel, 1987; Svensson, 1994);
- **Yield spread method:** estimation of the greenium through the calculations of distances between green and grey yield curves and between green and grey Z-spread curves (Lawler, 1982);
- **Panel regression method:** greenium's valuation conducted through a fixed-effect regression model (Zerbib, 2019).

This section explores the phases of data collection and matching method development and provides the main features of the three implemented methodologies, to assess the existence of a greenium and, controlling liquidity, analyze its determinants.

2.1. Data collection

The construction of the data sample has been developed on two different levels: the selection of green bonds and their conventional counterparts and the creation of a new category of synthetic bonds. The empirical analysis has required a larger sample for the NSS method (132 bonds in total, of which 44 green and 88 grey) and a shorter one for the other two methods. Therefore, both the yield spread method and the panel regression method have been calculated on a dataset consisting of 44 green bonds and 44 synthetic conventional bonds created

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Table 1. Main features of green bonds

Source: Bloomberg.

Field	Description
Security Status	Active
Use of Proceeds	Green Bond/Loan
Currency	Euro
Maturity	From 09/27/2018 to 09/27/2028
Issue Date	From 07/01/2013 to 09/27/2018
Coupon Type	Fixed
Is Still Callable	No
S&P Rating	Greater than or equal to BBB+
MiFID Bond Seniority Indicator	Senior Debt
Country Rating Grade on Transaction Date	Investment Grade

by interpolating a pair of conventional bonds with specific characteristics. Both the green bonds and original conventional bonds have been obtained by the Bloomberg platform. The dataset was developed between September and November 2018. The green bonds refer to specific performance parameters, selected to better capture their green nature and facilitate the comparison with conventional bonds.

The bonds' time horizon was shaped by the period of analysis: imposing a maturity between the first day of the research and 10 years later, and an issue date from the start date back to July 2013. This is because from 2007 to 2013, the trading volumes of green bonds, as well as the number of issues, were relatively small. The decision has been made to limit the analysis to the most recent years, as during this period, green bonds have become more established in the market, and the availability of data has increased exponentially.

Since the green bonds denominated in emerging markets, currencies tend to have more volatile and less stable spreads against local benchmarks than those denominated in euros or US dollars (Ehlers & Packer, 2018), the research was narrowed to a more specific geographical area, focusing only on bonds denominated in euros.

Finally, only non-callable bonds were selected to simplify the comparison of the yields: option-embedded securities require a more complex and specific valuation for each underlying, which includes the right to redeem at future maturities.

The resulting dataset consisted on 55 green bonds, which were further reduced to 44 during the construction of the final dataset. In the green bond sample, most of the bonds are senior unsecured, whit the remaining evenly split between local, government and company guaranteed[1] (Figure 1).

Figure 1 shows the sample distribution of collateral typologies for the number of bonds.

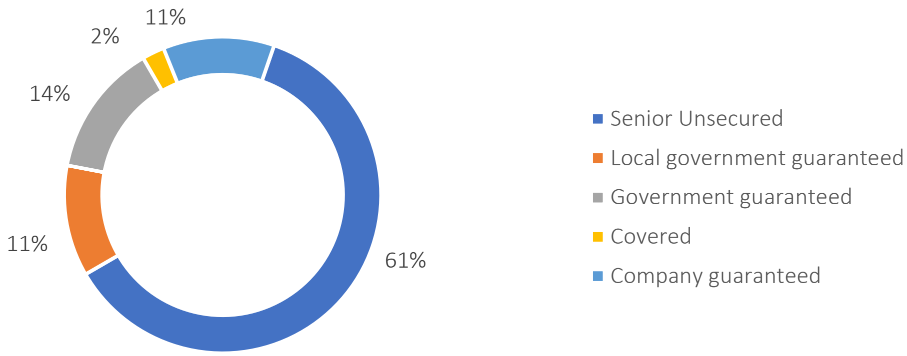

Figure 1. Collateral type distribution

1 A collateral requirement has been excluded because it could excessively damage the creation of a sufficiently large dataset.

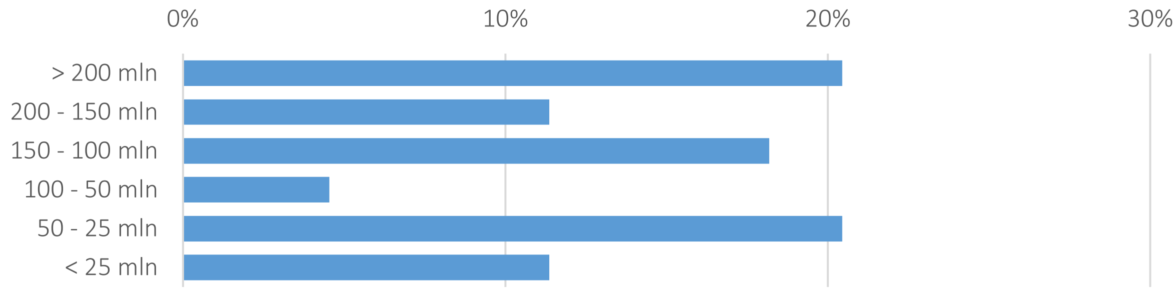

Figure 2. Sample distribution by number of bonds of issued volumes in million EUR

The issued amounts are between 50 and 100 million euros, with a minimum value of just over 20 million euros and a maximum of over 2 billion euros (Figure 2).

Figure 2 shows the distribution of the total issued amount.

If the distribution between rating classes by number of bonds appears quite homogenous, the distribution by volume of issuances shows that class AAA is predominant over the others (Figure 3).

Figure 3 shows the distribution of rating classes.

Lastly, almost all issuers belong to the financial sector, which dominates, with most of the companies being national commercial banks and federal credit agencies (Figure 4).

Figure 4 shows the industry distribution.

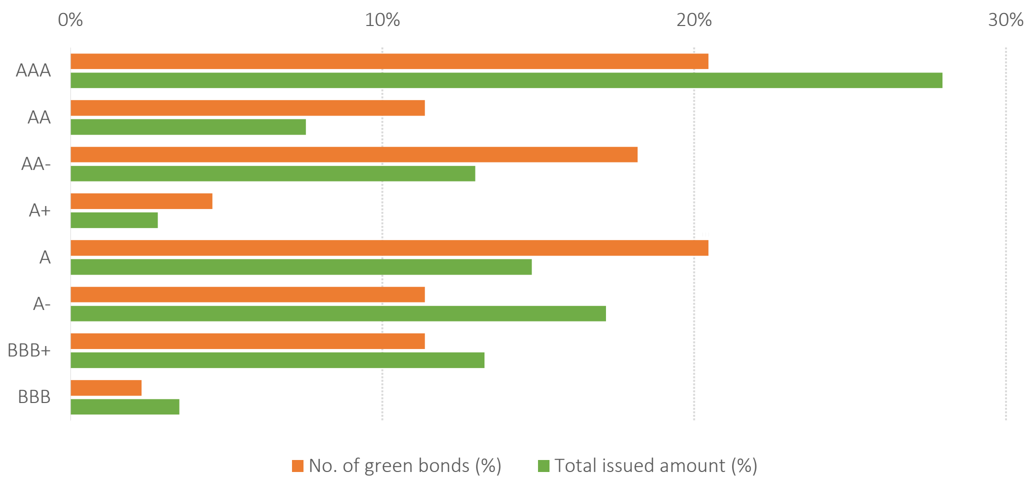

Figure 3. Sample distribution of rating classes by number of bonds and total issued amount

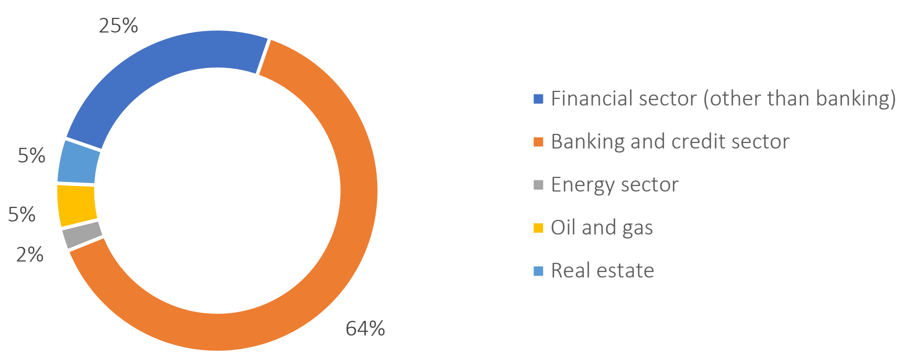

Figure 4. Sample distribution of sectors for the number of issuers

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2.2. Matching method

Once the green bonds had been classified, the next step was to identify their counterparts. Conventional bonds had to be selected with a similar profile to green bonds, considering factors that can influence the bond yield, such as currency, maturity, and rating. As it was impossible to find two identical bonds, a matching method was performed, combining a green and a grey bond after creating a sample of synthetic conventional bonds. Therefore, a pair of securities identical in all but one characteristic was matched to highlight differences and variations that occur in the latter.

The first step was to create a synthetic, conventional bond, i.e., a bond that does not exist on the market and has certain characteristics. Again, using Bloomberg, two corporate bonds were selected with the same characteristics as green bonds in terms of bond structure, currency, seniority, and coupon type. The two bonds had the same issuer and issuing country and were investment grade. Doing this, the variables left out of the matching procedure were those related to liquidity: the volume of the issued amount and the maturity.

To avoid matching matured long-term bonds with recently issued short-term bonds and to limit the liquidity premium embedded in the yield of the oldest bonds, the issue date and the maturity date were controlled. Since bonds tend to be less liquid as they approach the maturity date (Sarig & Warga, 1989), only conventional bonds with maturities no more than 3 years before or after the green bonds were selected. The same procedure was applied to the issue date.

Any green bond with less than two corresponding conventional bonds meeting the liquidity requirement was removed from the dataset. In total, 11 green bonds were dropped because it was not possible to find one or both the conventional bonds that met the time constraints. When the opposite situation occurred – more than two corresponding grey bonds – the Macaulay duration was used as a further selection filter. Bonds with Macaulay duration closer to that of the green bond were chosen for comparison. The descriptive statistics of the original conventional bond sample are represented in Table 2.

After defining the initial dataset of 44 triplets – one green bond and two conventional bonds – the sample was used in the analysis of the NSS method. Then, the conventional synthetic bonds were created by linearly interpolating the yields of the two grey bonds with the Macaulay duration. The final dataset consisted of 44 pairs of green and conventional bonds, identical in all but liquidity. The comparison in terms of descriptive statistics of the yield distribution for each class of bonds is shown in Table 3.

2.3. Nelson-Siegel-Svensson method

This first method, introduced by Nelson and Siegel (1987) and improved by Svensson (1994), consists in creating green bond and conventional bond

Table 2. Statistics of conventional bonds

Source: Bloomberg.

Variable	Min.	1st. Qu.	Median	Mean	3rd. Qu.	Max.
Issued amount	10988000	591495000	929940000	1145060946	1357845000	6767750000
Macaulay Duration	0,10958904	2,19331656	4,00732099	4,08548616	5,799037201	10,1082933

Note: Table 2 shows the descriptive statistics of the original conventional bond sample, the distribution of the sample for issued volume and Macaulay duration, and R calculations.

Table 3. Data sample statistics

Source: Bloomberg.

Bond category	Min.	1st. Qu.	Median	Mean	3rd. Qu.	Max.
Green bonds	–0,726022827	0,014425195	0,484854513	0,486549356	0,897589906	1,76354093
Original grey bonds	–0,612661457	–0,04307551	0,379162476	0,361295709	0,676230852	1,9018398
Synthetic grey bonds	–0,592865148	0,138200418	0,495764838	0,645475977	0,862648076	4,6634115

Note: Table 3 shows descriptive statistics of yield distribution for each bond category: green bonds (44), original grey bonds (88), and synthetic grey bonds (44); R calculations.

yield curves using the Svensson technique, an extension of the Nelson-Siegel model. This approach was used to calculate the green bond premium as interpreted in two different ways:

- as a spread between the performance of the two classes of bonds, and
- as a differential between the green and conventional bond Z-spreads.

The Nelson-Siegel-Svensson model is widely used by central banks to analyze the forward structure of interest rates. The approach is based on the observation of bond yields at a given time, on the creation of a weighted rate curve with certain parameters and on the minimization of rate residues' sum (Gilli et al., 2010).

According to the model, the yield y, at a certain time, is defined as:

$$y(t) = \beta_1 + \beta_2 \left[\frac{1 - \exp\left(-\frac{t}{\lambda_1} \right)}{\frac{t}{\lambda_1}} \right] + \beta_3 \left[\frac{1 - \exp\left(-\frac{t}{\lambda_1} \right)}{\frac{t}{\lambda_1}} - \exp\left(-\frac{t}{\lambda_1} \right) \right] + \beta_4 \left[\frac{1 - \exp\left(-\frac{t}{\lambda_1} \right)}{\frac{t}{\lambda_1}} - \exp\left(-\frac{t}{\lambda_1} \right) \right], \quad (1)$$

where y = yield of the bond; t = Macaulay duration; β_1 = parameter for the level of the yield curve; β_2 = parameter for the slope of the yield curve; β_3 = parameter for the curvature of the yield curve; β_4 = parameter for the magnitude of the second curvature factor; and λ_2 = parameters for the exponential decay rate (in years to maturity) of the slope and curvature factors

The parameters are set to minimize the sum of the yield standard deviations. Specifically, β_1 is independent of the time variable and, for this reason, is often interpreted as the long-term level of return; 2, 3, and 4, on the other hand, are dependent on the t variable's trend and decrease as the t variable increases, under the influence of the parameters λ_1 and λ_2. According to the model, by setting λ, a fixed factor loading on a given maturity was imposed (Wahlstrøm et al. 2022).

The analysis was conducted by defining the greenium, firstly, as the difference between the yield rates and, secondly, as the difference between Z-spread of the two bond categories.

To define the time horizon, the duration of the total bonds was ordered from the smallest value of 0.008 to the largest one of 10.1083. Each duration of the bond i was assigned to the corresponding yield, considering the green bonds' rate curve and the grey one separately. The NSS curve and its residues with bond yields were estimated by minimizing the sum of the residues by adjusting the parameters β_1, β_2, β_3, β_4, λ_1, and λ_2. For each distribution of the yields as a function of the duration, a trend curve of the yields was configured. Thus, it was possible to estimate what the yields of green bonds would be if they had the same duration as conventional bonds, and vice versa.

2.4. Yield spread method

The model measures the greenium by comparing the yield distribution of green bonds and synthetic conventional bonds. The aim is to minimize the liquidity risk that emerges when considering securities with different maturity. Indeed, the use of synthetic conventional bonds shows what the yield of a conventional bond would be if it had the same duration as a green bond. On a dataset of 44 pairs of bonds, the yield spread is calculated as the difference between the yields of each category with the same duration.

2.5. Panel regression method

The method examines the existence and the extent of the greenium by implementing a fixed effects regression. As described above, the constraints limiting the difference in liquidity between green and grey bonds were already set in the construction of the dataset; however, an additional control

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was introduced to include a proxy for the variable in estimating the premium. Notably, the difference in the bid-ask spread between green and grey bonds was used as a liquidity proxy. This measure is a valid indicator of the trading volume of a given security: a larger bid-ask corresponds to a lower trading volume, hence a lower liquidity. If a bond is subject to high transaction costs, reflected in the bid-ask price differential, it loses its attractiveness: potential traders in the market will turn to other securities, reducing the number of trades in that security and thus the liquidity in the market (Febrian & Herwany, 2008). Since the synthetic conventional bond is created by interpolating two original conventional bonds, its bid-ask spread must be considered as the difference between the values of their bid and ask prices.

The bid-ask (*BA*) of the synthetic conventional bond (*CB*) is represented as follows:

$$\Delta BA_{i,t}^{\overline{CB}} = \frac{d_1}{d_1 + d_2} \Delta BA_{i,t}^{CB_1} + \frac{d_2}{d_1 + d_2} \Delta BA_{i,t}^{CB_2}, \quad (2)$$

with $d_1 = |durationGB - duration\ CB_1|$; $d_2 = |durationGB - duration\ CB_2|$; where for each bond i at the time t: $\Delta BA_{i,t}$ = bid-ask spread; $durationGB$ = Macaulay duration of the green bond; $duration\ CB_1$ = Macaulay duration of the first conventional bond; $duration\ CB_2$ = Macaulay duration of the second of conventional bond.

Hence, the liquidity differential – the independent variable in the fixed effects regression – was calculated. In formula (3), the liquidity differential is calculated as the bid-ask spread differential between green and synthetic conventional bond.

$$\Delta liquidity_{i,t} = BA_{i,t}^{GB} - BA_{i,t}^{\overline{CB}}, \quad (3)$$

where for each bond i at time t: $\beta \Delta liquidity_{i,t}$ = liquidity differential; $BA_{i,t}^{GB}$ = bid-ask spread of the green bond; $BA_{i,t}^{CB}$ = bid-ask spread of the conventional bond.

The regression line has thus been configured as suggested by Zerbib. The yield premium is to be interpreted as the unobserved effect of the regression model:

$$\Delta \tilde{y}_{i,t} = p_i + \beta \Delta liquidity_{i,t} + \varepsilon_{i,t}, \quad (4)$$

where for each bond i at time t: $\Delta \tilde{y}_{i,t}$ = yield spread differential between green and synthetic conventional bond; p_i = yield premium, the unobserved effect of the fixed-effects regression; $\beta \Delta liquidity_{i,t}$ = bid-ask spread differential between green and synthetic conventional bond; $\varepsilon_{i,t}$ = error term.

The model allows coherent estimates of fixed effects presented as a vector of T constant elements equal to p_i, which, therefore, ranges over a single dimension (t is constant). The vector represents the individual effect, that is, the set of specific characteristics for each individual and that do not change in time (it must therefore be valid that: $a_i \neq a_j$ for each $i \neq j$).

3. RESULTS AND DISCUSSION

Depending on the methodology implemented, the greenium changes in sign and magnitude. This section illustrates the study's main findings, describing the determinants that influenced the magnitude and sign of the greenium and the strengths and limitations of the three methodologies.

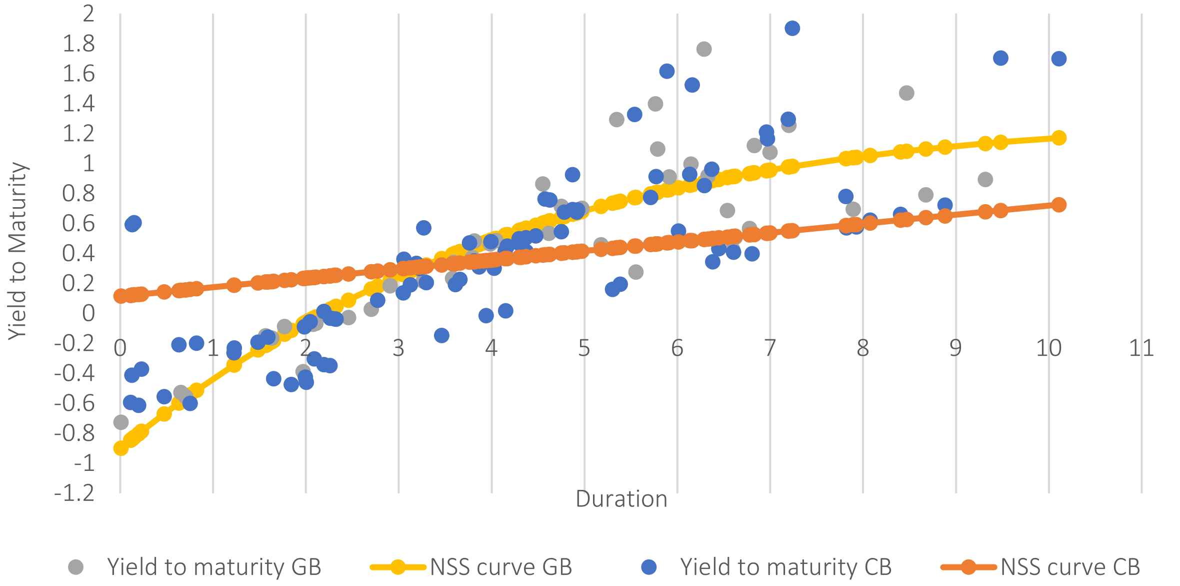
3.1. Nelson-Siegel-Svensson method

The NSS model was performed using a sample of 44 green and 88 conventional bonds, with similar characteristics in terms of issuer, rating, maturity, and coupon type. The sample includes a global premium of +37, 89 b.p., measured as the distance between the yield curves of green and conventional bonds with the same duration.

Another way to compare green and grey bonds is to look at the Z-spread of the two stock samples. In this case, the results are slightly different from the previous performance: indeed, the yield curve has a linear trend, and the premium is positive (+10.62 b.p.) and constant over time (Figure 6).

A positive green bond premium means that green securities have, on average, a higher yield than their conventional counterparts. This could be explained by looking at liquidity: the green bond market is still young and small-scale, it has a restricted number of participants, and it lacks standardization, which leads to high transaction costs. Thus, it is possible to conclude that green bonds

Source: Bloomberg.

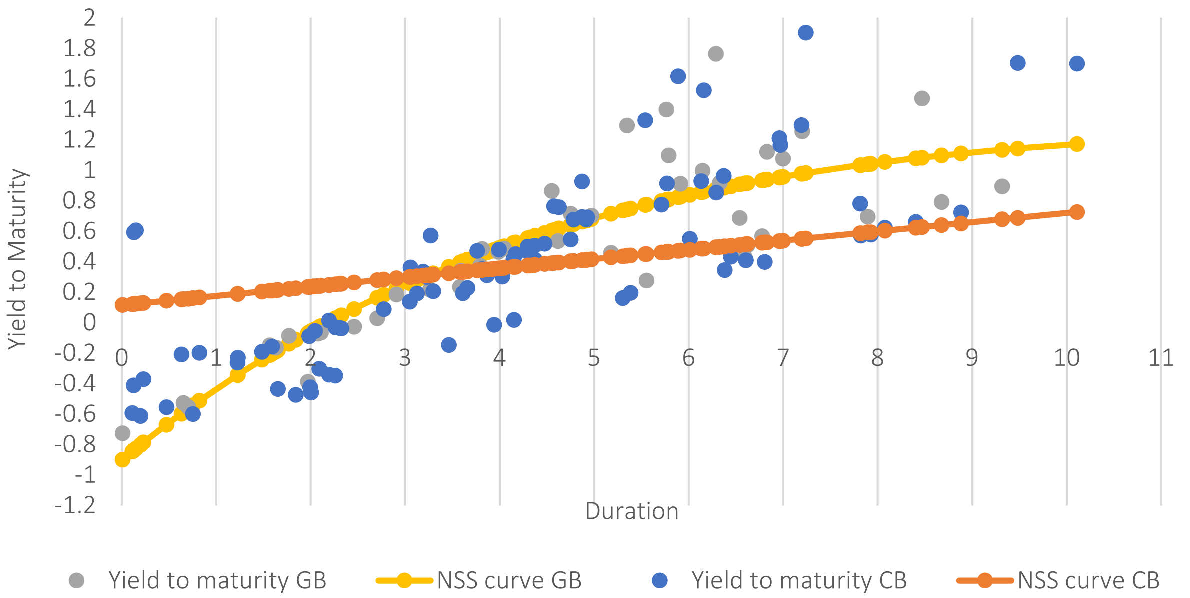


Note: The distribution of the yield spread between green and conventional bonds is analyzed using the Nelson-Siegel-Svensson method. The average green premium is positive and equals +37.89 b.p. Excel calculation.

Figure 5. Nelson-Siegel-Svensson method: Yield spread differentials

are less liquid than grey bonds and that investors ask for higher yields as compensation for the risk.

There could be another explanation as regards the difference between the two approaches used – differential in the yield curves and differential in the Z-spread curves. Defining the Z-spread as a measure of riskiness between an investment in a specific bond and one in a zero-coupon bond, it is possible to imagine that this risk can vary for several reasons, related, for instance, to liquidity, volatility, and the interest rate curve. If even only one of these variables changes over time, then this could cause a distortion with



Note: The distribution of Z-spread differential between green and conventional bonds is analyzed using the Nelson-Siegel-Svensson method. The average green premium is positive and equal to +10.62 b.p. Excel calculation.

Figure 6. Nelson-Siegel-Svensson method: Z-spread differentials

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reference to the methodology of "mere" analysis of the yield. This would explain the different amounts of the premium.

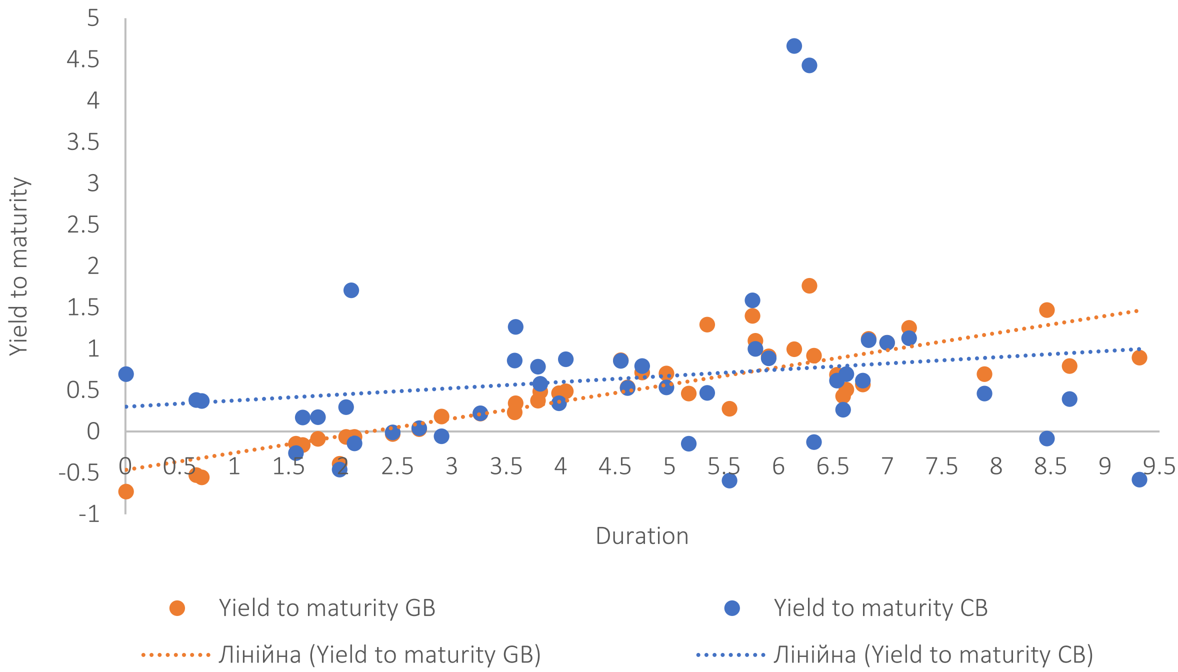
The NSS method allows optimal comparison of bonds paying different coupons. However, there are several weak points in the NSS method. To begin with, the quality of the model strongly depends on the quality of the sample (Schmitt, 2017). Because of the nature of the methodology, the analysis considered green and grey bonds with different durations – to build the NSS curve based on the related yields' distribution – but this has led to a lower control of the duration bias[2]. Moreover, Gilli et al. (2010) found two main issues related to the calculation of the model: first, the optimization problem is not convex and has more than one local optimum, which generates difficulties in obtaining appropriate values of the parameters through the available statistical packages. Secondly, the optimization is not bound, so the estimated parameters become unstable in the presence of small disturbances in the data (Gilli et al. 2010).

3.2. Yield spread method

In contrast to the previous methodology, a negative premium has emerged, with green bonds having, on average, a lower return by –15.89 b.p. (Figure 7). In this way, it can be inferred that there is an advantage in issuing green bonds against investing capital in these financial instruments. One reason for this phenomenon could be the pressure of high transaction costs, the perception of higher risk and the small number of green market participants exert on the yield of environmental bonds. However, the excess demand for green investments in the market, despite the possibility for issuer to offer green bonds at lower interest rates, may lead to divergent conclusions. This contradiction is important to keep in mind when drawing conclusions from the study.

The Yield Spread Method (Lawler, 1982) has several limitations. When setting up the model, the hypothesis to be verified is that the yield differential between the two bond categories is determined by their specific characteristics. To get a better comparison sample, the synthetic conventional bonds' dataset

Source: Bloomberg.



Note: Yield distribution of green and synthetic conventional bonds. The average green premium is negative and equals –15.83 b.p. Excel calculation.

Figure 7. Yield spread method: Yield distribution

2 In this model, green and grey bond have different duration. This was necessary in order to build the NSS curve on the yield basis and with reference to a complete timeline for each security.

was set, containing less dissimilarities. Then, bonds with the same characteristics were matched, leaving only liquidity factors to study the influence on the yield premium. These constraints were also imposed in the sample used in the previous approach (NSS method), but by creating a synthetic grey bond, the discrepancies between bonds were controlled by eliminating the bias caused by the different durations. However, the advantage of less dispersion was offset by a greater reliance on the goodness of the bond selection model. In fact, the more constraints are imposed on the data, the more bonds are excluded from the sample.

In addition, although the approximation for shorter maturities (up to one year) is not sometimes adequate enough, numerous studies confirm the ability of the NSS model to capture the correct yield values and to optimally estimate the term structure of interest rates over time (Kazemie, 2014). Moving away from this approach is not necessarily the best choice regarding investigation accuracy. Finally, liquidity has been considered merely implicit in this model, although being so important to define the yield differential: a negative greenium indicates a lower green bonds' yield, and this result appears incoherent with previous assumptions about liquidity. For this reason, the analysis further focused on liquidity's influence with the Panel Regression Method.

3.3. Panel regression method

The third method, mainly applied by Zerbib (2019), processed a regression to calculate the within regression and to investigate the nature of the green bond premium. The variables of the model were represented by the dependent variable y consisting in the yield differential, and by the independent variable x, that is, the variation of the bid-ask spread (Table 4).

Once the linear regression was set, panel data was created, on which the fixed-effects regression was performed. To assess the quality of the estimated model, it was helpful to compare it with others, such as the pooled model, where there is no difference between individuals, the random-effects model, which incorporates a zero-variance hypothesis for the randomly extracted individual variable, and the model based on the between estimators, which regresses the differences between individuals. The p-value showed that the fixed-effects model was the best choice in all cases. In particular, F-test and Hausman test were performed. The Hausman one tests the fixed-effects model against the random-effects one. Hence, it is possible to understand the affinity of the coefficients of the two models by verifying the correlation between constant terms and the regressors, thus checking the efficiency of the fixed-effects estimator[3]. The robustness of the estimates of the standard errors was also tested to assess the presence of heteroscedasticity, i.e. the uneven dispersion of data with different variances. Verifying the heteroscedasticity of residues is necessary to detect problems with incorrect specification of the model, such as omission of relevant variables[4]. The Breusch-Pagan test[5] was also conducted, as well as the Breusch-Godfrey/Wooldridge test, to check the presence of serial correlation[6]. The analysis of the results of the regression revealed that, with an increase of 1 basis point in

Table 4. Panel regression method: Statistics of the variables

Source: Bloomberg.

Variable	Min.	1st. Qu.	Median	Mean	3rd. Qu.	Max.
$\Delta\tilde{y}_{i,t}$	–3,66603003	–0,00860766	0,04806280	–0,15399840	0,10123744	0,88714250
$\Delta liquidity_{i,t}$	–3,53238656	–0,05530832	0,01051422	–0,09358320	0,09293784	0,48290835

Note: Descriptive statistics of dependent variable $\Delta\tilde{y}_{i,t}$ and independent variable $\Delta liquidity_{i,t}$ R calculations.

3 In this case, the null hypothesis (no fixed effects) is rejected. The same results emerge from the p-value of the F-test comparing fixed-effect regression with pooled OLS regression.

4 Usually, regression models imply errors with same variance, but if it is not, i.e., heteroscedasticity, this is reflected on residues. Thus, it is necessary to conduct an opportune test and a coherent standard error estimate to permit the adaptation of the model with the residues.

5 Adaptation test of the model with the residues; the null hypothesis is homoscedasticity.

6 Fixed-effect model regression provokes serial correlation of error terms and so lower efficiency. The Newey-West test gives an estimate of the covariance matrix controlling both serial correlation and heteroscedasticity.

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Table 5. Panel regression method: Statistics of the greenium

Source: Bloomberg.

Variable	Min.	1st. Qu.	Median	Mean	3rd. Qu.	Max.
p_i	–3,13482521	–0,04946808	0,01003878	–0,1714865	0,07260248	0,88953010

Note: Descriptive statistics of green bond premium as an unobserved effect of panel regression: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta liquidity_{i,t} + \varepsilon_{i,t}$,. R calculations.

the variation of the bid-ask spread of the bonds for each issuer, there is a decrease in the yield differential equal to –2,3873 b.p. By extrapolating the descriptive statistics of the fixed effect, what emerges is a green bond premium equal to –17,1487 b.p. on average (Table 5).

However, the fixed-effect regression shows a far too low R-squared (the value is close to zero). This means a poor ability of the independent variable – the liquidity in terms of bid-ask spread – to explain the dependent variable – the yield spread differential. At this point, the above-defined model has to be overcome and implemented with other variables through a dedicated study of significance.

Zerbib suggests the integration of volatility as a second independent variable. However, after a robustness test of the standard error, the author rejects the idea of its relevance in determining the yield differential (Zerbib, 2019). Nevertheless, the results seem to recall the conclusions of Wulandari et al. (2018) about a correlation between liquidity risk and the yield spread. In any case, such relation appears to lose its significance in more recent years, probably because of the negative link between liquidity and the age of bonds.

Moreover, liquidity's low explanatory power could be explained by the presence of noise disturbing its grade of reliability: according to Helwedge et al. (2014), the factors used as proxies in the yield spread analysis often capture both liquidity and credit risk. They also present a certain variability over time, making separating the two components during empirical analysis even more complex.

The fixed-effect regression method aims to exceed the limits of the previous approach by imposing an additional liquidity requirement. However, the concerns related to the quality of the collected data are, in this case, even more decisive in defining the accuracy of the model, since the selection of filters used to identify the pairs of conventional bonds becomes a parameter of sensitivity to model precision.

When comparing the results obtained from each methodology, it emerges that there are many elements that can be further adjusted.

First, it is worth noticing in the reference dataset that some requirements have been intentionally excluded from the selection process, but their omission could have affected the final results. The proportionality constraint between the issued volume of the green bond and that of the grey bond was avoided to leave a liquidity movement margin. Still, the decision could have excessively influenced the liquidity premium embedded in the bond yield. A deeper analysis should also introduce the issued volume as an additional constraint and the same type of guarantee for green and grey bonds as a comparability requirement. However, it is important to remember that the more limitations are placed on the final sample, the higher the odds that such constraints will degrade the quality of the estimates.

Furthermore, some characteristics of bond taxation, such as the calculation of tax advantages or the different taxation imposed by the various countries, could affect the yield premium, and its omission could distort data interpretation.

Lastly, the investigation of yield premium determinants does not consider the volatility of securities. If green bonds, as it seems, are less volatile than their conventional counterparts, investors will tend to keep the more stable green bonds in their portfolio. Therefore, in case of a negative premium, lower volatility could be considered as a compensation tool for the lower return: excluding it from the analysis criteria could represent a mistake.

CONCLUSION

This analysis aims to determine whether a yield spread exists between green and conventional bonds and which factors may influence it. Applying three different methodologies, the research provides a solid analysis of the correlation between liquidity and yield spread, highlighting strengths and limitations of each method.

A green bond premium emerges from all the three different models performed, but its entity, sign and real determinants are still uncertain. Besides, depending on the sample used and the variables linked to the yield differential, also the quantum of the observed premium changes.

Using the Nelson-Siegel-Svensson method, the premium was calculated in terms of both yield spreads and Z-spreads differentials. The two different approaches show a positive greenium, although with a different extent: +37.89 b.p. and +10.62 b.p., respectively. This could be due to high transaction costs, the perception of higher risk, and the limited size of the green bond market.

The other two approaches, namely calculating the distances between green and grey yields and implementing the fixed-effects regression model, produced different results: in both cases, the premium is indeed negative, at around –16 b.p.

The similarities between the results of the last two approaches may be attributable to the same composition of the data sample but also to a lack of effectiveness of the liquidity used in the panel regression in explaining the yield differential.

The study thus provides the basis for refining the analysis, both by including new constraints and variables in the construction of the dataset – such as tighter restrictions on the issued amounts, the control of volatility, or the calculation of fiscal effects – and by examining the impact of liquidity differently, using different measures to calculate this variable.

The factors influencing the green bond yield can be various, and much work remains to be done to obtain comprehensive results. A long-term approach is needed to assess the green yields and the efficiency of the market while constantly monitoring the expansion of the green bond sector into a large and developed market.

AUTHOR CONTRIBUTIONS

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