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Brown and Green – What's the Yield in Between?

A quantitative study on yield spread differences between green and conventional bonds on the Swedish real estate market.

by

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ABSTRACT

The growing need for green investments has contributed to the increased issuance of green bonds. This research investigates if green bonds are priced differently from conventional bonds by measuring yield spread discrepancies. To estimate the potential yield premium, we perform a matching method and a fixed effect generalized least squares estimator from October 2016 to December 2020. We observe three time periods to account for the impact of the COVID-19 crisis, and our results show a decreasing green bond premium over time. Ultimately, we notice an indication of a no longer existing green bond premium in the real estate sector.

Keywords: green bond premium, real estate sector, matching method, generalized least squares, z-spread, bid-ask spread

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1. Introduction

In December 2015, the United Nations parties agreed to hold the rise in global average temperature below 2°C and strive to limit the increase to 1.5°C in the Paris Agreement (OECD, 2017a). Thus, the shift of allocation on carbon-intensive to low-carbon climate-resilient (LCCR) investments have been emphasized (Nicol et al., 2018). Green bonds align with LCCR investments, and its market is continually growing with USD258.9bn issued in 2019, a 51% increase from 2018 (Almeida, 2019). The definition of a green bond is capital raised toward environmentally sustainable projects (International Capital Markets Association (ICMA), 2018), which separates green from conventional bonds (henceforth *brown* bonds).

The Swedish green bond market opened in 2013 when Vasakronan issued the first SEK denominated green bond (Filkova, 2018). In 2016, the Swedish government wrote about raised demand for green bonds (Swedish Government, 2016), and since then, the attention has risen consequently for the green bond market. Further on, the Swedish parliament agreed upon the importance of sustainable finance and the critical role the financial market plays in the transition to a greener market (Swedish Government, 2019a), hence the importance of green bonds.

In 2019 the government-appointed Swedish National Debt Office raised sovereign green bonds (Swedish Government, 2019b). A proposal was previously debated and opposed by the Sweden National Debt Office due to budgetary limitations (Swedish National Debt Office, 2018). Finally, the first green sovereign bond issuance was completed on September 1 in 2020 (Swedish National Debt Office, 2020).

In March 2020, COVID-19 struck the world and had an extreme impact on the financial economy. Sweden's corporate bond market suffered from a crush in demand, resulting in a substantial rise in risk premiums and a substantial deterioration in liquidity (The Riksbank, 2020).

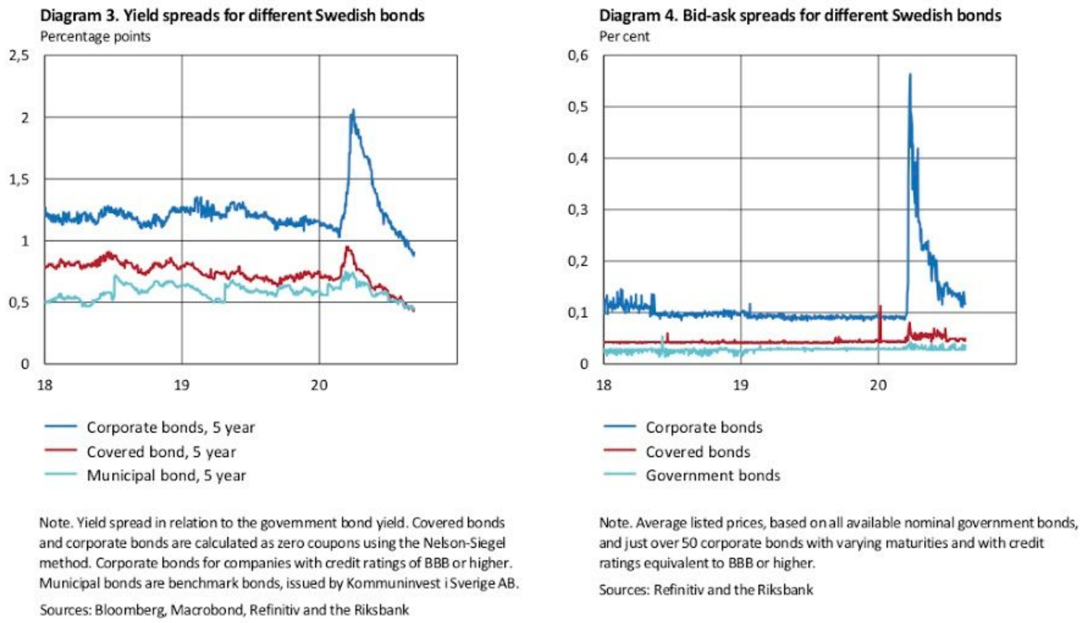

Figure 1 and 2. *Yield spreads and Bid-ask spreads for different Swedish bonds (The Riksbank, 2020). Swedish corporate bonds during the COVID-19 pandemic.*

The financial crisis of 2008 had similar characteristics as the COVID-19 crisis regarding liquidity on the corporate bond market. Investors wanted to liquidize their assets, which created an extreme rise in the bid-ask spreads, pushing up the yield spreads (Friewalda et al., 2011). Observing figures 1 and 2 (adapted from The Riksbank, 2020), we can confirm that the unusual market movement in the spring of 2020 follows a pattern similar to what is previously described. Furthermore, this affects the comparability to previous studies conducted before February 2020 in this field of study.

The Global Sustainable Development Report conducted in 2019 shows that real estates' are responsible for 40% of the world's energy consumption (United Nations, 2019). In response, 34,92% of the bonds issued in 2016 in the real estate industry have been green (Bloomberg, 2020). Moreover, the Swedish government has been explicit regarding a more sustainable building process within the real estate sector (Swedish Government, 2019a). As the real estate sector accounts for a major part of the Swedish green bond market, and as green bonds account for a major part of the real estate bond market, a comparison between the yield of green and brown bonds would be interesting and up-to-date. Comparisons of the aforementioned have been made, although no one has explicitly investigated the real estate sector.

Reports in the field of green bonds yield discrepancies lack a unanimous conclusion regarding the green bond premium, even to the extent of whether it is positive or negative. It is difficult to determine whether the reason is the difference in choice of liquidity proxies, delimitations, observed time intervals, or methods. Nevertheless, we believe the lack of unanimity gives us reason to investigate this topic further. Moreover, the green bond market has had rapid growth in issuance over the last two years, creating a possibility to find a new and narrower delimitation, which we will further discuss later in this section.

One of the most acknowledged papers in this field of study, written by Oliver Zerbib in 2019, investigates the *greenium* (i.e., green bond premium) on the global secondary market using a matching method and a cross-sectional fixed effects panel regression that is estimated by generalized least squares and ordinary least squares. The matching method consists of creating identical synthetic bonds to green bonds regarding bond characteristics in order to compare yield differences. Studying a sample from 2013 to 2017 and using a bid-ask spread and issue amount as proxies for liquidity, he estimated a result of -2bps green bonds premium.

Hyun et al. (2020) and Bour (2019) used a method that is similar to Zerbib (2019), both in terms of method and liquidity proxies. Both papers studied a global sample, but Hyun et al. (2020) analyzed data between 2010 and 2017, while Bour (2019) analyzed data from 2014 to 2018. They reported a green bond premium of -6bps and -23.2bps, respectively.

Nanayakkara and Colombage (2019) investigated the greenium through an option-adjusted spread as a dependent variable to measure the credit spread between the years 2016 and 2017. They accounted for macroeconomic and global factors in their model but did not involve a liquidity proxy. Another paper that did not account for liquidity differences between green and brown bonds in their model is Gianfrate and Peri (2019). They analyzed a sample from 2013 to 2017. Similar to Zerbib (2019), once again, both studies applied a matching method for the global market and reported a greenium of -63bps and -5bps.

Bachelet et al. (2019) and Preclaw and Bakshi (2015) compare the green bond premium on the global secondary market. Their control for liquidity differs in their respective models. Bachelet et al. (2019) used bid-ask-spread, issue amount and zero-trading-days, while Preclaw and Bakshi (2015) controlled for the date of issuance. Additionally, Bachelet et al. (2019) studied a sample from 2013 to 2018 and Preclaw and Bakshi (2015) analyzed data between 2014 and 2015. Ultimately, they reported 14,5bp and -17bp.

Baker et al. (2018) and Karpf and Mandel (2018) researches the secondary U.S municipality market, while Baker et al. also investigate the U.S corporations as issuers. Both papers investigated the green bond premium with an OLS regression, the amount issued as a control for liquidity, and studied data from 2010 and 2016. On the contrary, Karpf and Mandel (2018) studied the premium using an Oaxaca-Blinder decomposition and used the number of transactions in the last 30 days for each bond to measure liquidity. Oaxaca-Blinder decomposition explains *"the difference between the total rates of two groups in terms of differences in their specific rates and differences in their composition"* (Kitagawa, 1955, pp. 1169). Baker et al. (2019) disclosed a negative premium of 7bp, while Karpf and Mandel's (2018) result was a positive premium of 7.8bp.

To conduct a fully unbiased comparison between brown and green bonds, it is required that the bonds are issued on the same day from the same company, where every aspect of the bonds are identical, which has not yet been done. Talking to Ulf Pettersson (Chief of Fixed Income at Den Norske Bank (DNB), phone interview, December 8, 2020), he states that when he has conducted comparisons of green and brown bonds, he senses that there exists a green bond premium of approximately 2-3bps. Furthermore, he suggests, as previously said, that it is required to compare two identical bonds to conduct a fully reliable result. Asking Pettersson (2020) whether he believes that the green bond premium could have decreased during the past years, as the number of issued green bonds has increased faster than the demand on the prior, Pettersson (2020) argues that it is hard to tell whether the supply has increased more than the demand. He senses that "*the focus from the buying side has increased at least as much*" (Pettersson, phone interview, translated from Swedish, December 8, 2020). Referring to what Pettersson said, our method, and delimitations, could be argued as the closest one can get to an identical bond comparison considering the non-existence of an identical bond pair.

Table 1: Pre-literature study

Authors:	*Premium:*	*Method:*	*Interval:*
Zerbib (2019)	-2bps	*Matching method and fixed effects*	*2013-2017*
Hyun et al. (2020)	-6bps	*Matching method and fixed effects*	*2010-2017*
Bour (2019)	-23.2bps	*Matching method and fixed effects*	*2014-2018*
Nanayakkara and Colombage (2018)	-63bps	*Matching method and fixed effects*	*2016-2017*
Gianfrate and Peri (2019)	-5bps	*Matching method and fixed effects*	*2013-2017*
Bachelet et al. (2019)	14.5bps	*Matching method and fixed effects*	*2013-2018*
Preclaw and Bakshi (2015)	-17bps	*OLS*	*2014-2015*
Baker et al. (2018)	-7bps	*OLS and fixed-effects*	*2010-2016*
Karpf and Mandel (2018)	7.8bps	*OLS and Oaxaca-Blinder decomposition*	*2010-2016*

Our study will take a new position among previous studies conducted on this topic, with an unexplored delimitation and an alternative measure of yield, which leads us to our research question:

Does a yield premium exist for SEK denominated green bonds issued by real estate companies on the secondary market?

Our primary contribution to the research field of green bonds yield discrepancies is a result conducted with the most frequently used method (**Table 1**) – a matching method followed by a cross-sectional fixed effects panel regression. To further describe, we will create synthetic bonds consisting of two brown bonds and pair them with a similar green bond in terms of bond characteristics. Furthermore, we will estimate the yield spread difference between the two with a fixed effect generalized square regression, where the mean of the fixed effects will be interpreted as the green bond premium.

An additional contribution is our unexplored delimitation – the Swedish secondary market for SEK denominated real estate bonds. We believe that our paper will provide a new result since no previous study has analyzed a delimitation this narrow and with data until 2020. Our observed time period is between 2016-10-13 to 2020-11-30, an observation period none of the previous studies have investigated. To be able to compare with previously reviewed literature and account for the effect of the COVID-19, we will study two additional time periods. One before COVID-19 affected the financial market, i.e., between 2016-10-13 and 2020-01-31 (henceforth the *Pre-COVID-19 period*), and another when the previous studies have been conducted, i.e., between 2016-10-13 and 2018-12-31 (henceforth the *Early period*). Our original time period will be referred to as the *Entire period* (2016-10-13 to 2020-11-30). Furthermore, our study will consider a Zero-volatility spread (henceforth *Z-spread*) as our dependent variable, in contrast to previous papers that have studied the ask yield, such as Zerbib (2019) and Bachelet et al. (2019), to mention a few.

2. Data and Matching Method

2.1. Data Description

In order to quote a bond, the most conventional method of pricing is with the yield. It is determined by the coupon divided by the bond price (Choudhry, 2004). A frequently used way to measure yield is yield-to-maturity (YTM). YTM is adequate to the internal rate of return of the bond (Choudhry, 2004). Since YTM does not include a benchmark curve, it is not an appropriate measure of yield in our case as investors strive to find a fair, relative measure of the yield (Choudhry, 2006a), i.e., a yield relative to a benchmark curve.

Zerbib (2019) and Bachelet et al. (2019) performed a method to measure the difference in ask yields between bonds as their dependent variable. Pianeselli and Zaghini (2014) and Zaghini (2019) use the asset swap spread (ASW) as the yield spread instead of the other alternatives. The benefit of using the ASW as the yield spread is the inclusion of other parameter effects, i.e., a benchmark curve. Interviewing Ulf Pettersson at Den Norske Bank (Pettersson, phone interview, December 8, 2020), he suggests that the ASW does not account for the different convexities in bonds depending on whether the bond is traded below or above par. Thus, the comparison becomes skewed since the ASW will react differently to price changes for each bond.

Zerbib (2019) and Bachelet et al. (2019), to mention a few, use ask yield as their dependent variable, which could be biased as it does not include a benchmark curve. Whereas the aforementioned authors use yield differences as their dependent variables, it could be argued that the interest rate of treasury bills should be the same constant for every bond and therefore eliminated when comparing differences between flat yields. However, the fact that every bond has different maturities implies that every bond must have different treasury bills in relation to their maturity.

To account for a benchmark curve and avoid convexity issues simultaneously, we look at further options of potential measures of yield, such as the Z-spread. The Z-spread could be defined as the excess implicit yield; in other words, an yield spread solved from a formula consisting of a benchmark curve, swap spread, coupon and the bond price. Hence, the Z-spread both accounts for treasury bills based on the bonds' maturity and are unexposed to the ASW related convexity issues. Therefore we will use *Z-spread* as our measure of yield between green and brown bonds following Henide and Meyer (2020), who point out the same advantages as previously stated. Pettersson (2020) also suggests Z-spread as a suitable variable to compare when analyzing bond discrepancies. Bloomberg define the Z-spread as *"a bond’s ’constant spread’ over the benchmark zero-coupon swap curve"* (Bloomberg, 2020, n.p.).

As Z-spread accounts for a benchmark curve in relation to the bond’s maturity, we argue that it is a more appropriate measure than ask yield, considering that traders tend to observe the Z-spread when measuring relative values according to Choudhry (2006b). He presents the Z-spread as shown in equation (1), where one extracts the Z-spread using the formula.

$$(1)\quad Price = \sum_{i=1}^{n} \frac{CF_i}{(1+((S_i + T_i + Z)/m))^i}$$

Where:

$Z = Z\text{–}spread$

$CF_i = Cash\ flow\ for\ each\ period$

$S_i = Swap\ spread$

$T_i = Yield\ of\ treasury\ bill$

$m = Frequency\ of\ coupon\ payments$

$n = Number\ of\ interest\ periods\ until\ maturity$

The bond price, hence the yield, is correlated with liquidity due to the risk the bondholder takes, as he may not be able to sell the bond for a preferable price when the bondholder intends to sell the bond. The risk of low liquidity is, therefore, compensated with higher bond yields and vice versa. As the liquidity is correlated with the price (See Chen, Lesmond and Wei, 2007), Fontaine and Garcia (2011) and Fong, Holden, and Trzcinka, 2017), we follow Zerbib (2019) and include it as an explanatory variable. There are different ways to proxy liquidity, such as LOT (i.e., trade size), percentage zeros and bid-ask spreads (Fong, Holden & Trzcinka, 2017).

Fong, Holden and Trzcinka (2017) find the bid-ask spread to be the most significant proxy of liquidity after analyzing LOT, percentage zero and bid-ask spread. Hence, this study will utilize *bid-ask spread,* following Zerbib (2019) and Bachelet et al. (2019), as a proxy for liquidity.

Besides liquidity, the number of days to maturity also affects bond yields (Choudhry 2004); therefore, this paper accounts for the prior factor to eliminate the maturity bias. The matching method is used partly for this reason, i.e., the method involves an interpolation or extrapolation of the two brown bonds' yield to the green bond's maturity, resulting in eliminating the maturity bias.

The default risk, or credit risk, is also correlated with bond yield in the sense that high-risk bonds give the bondholders a risk premium in the form of higher bond yields and vice versa. The correlation between default risk and bond yield is a known relationship documented by Longstaff, Mithal and Neis (2005). Zerbib (2019) approached the risk of default by using Standard & Poor's (referred to as S&P), Moody's and Fitch's credit ratings to sort the bonds into six categories. As we use a matching method where one of the requirements is that the bonds have the same issuer, we eliminate credit risk biases.

To define whether a bond is green or brown, we use CBI's Climate Bond Standards and ICMA's Green Bond Principles as the green bond label. This is similar to the OECD (2017b) and the European Commission (Cochu et al., 2016). Thus, this positions CBI's principles as the fundament for the current green classification.

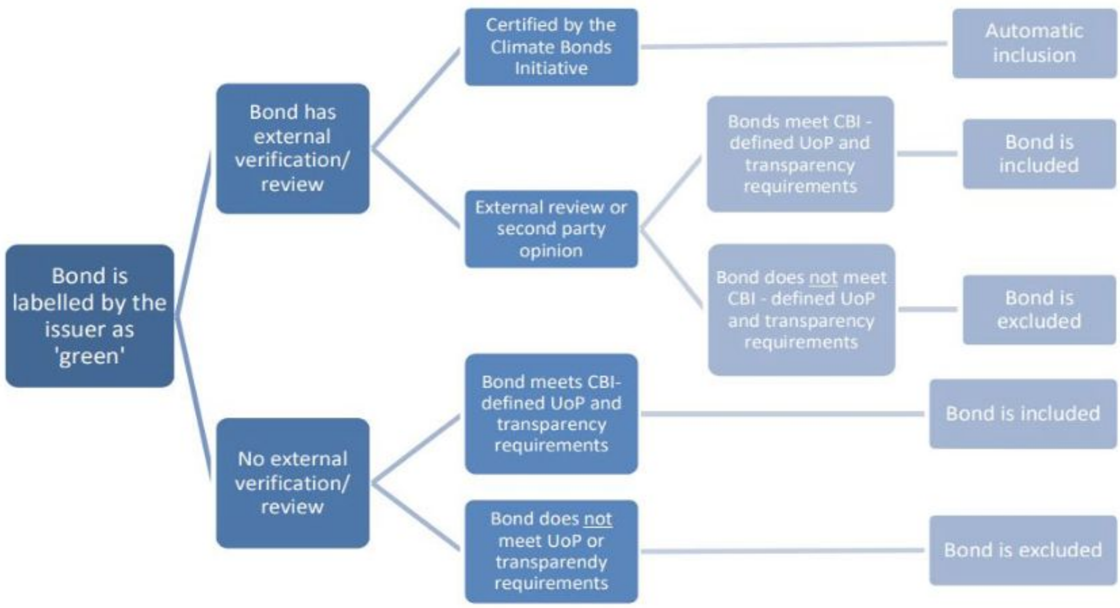

Figure 3. *Green bond database inclusion assessment explained (CBI, 2018).*

Figure 3 (adapted from CBI, 2018) shows the inclusion process of a green bond in CBI's system, which differs from Bloomberg's. Bloomberg provides a green tag for a bond in the use of proceeds field if the issuer:

> *a) self-labels its bond as 'green', or b) identifies it as an environmental sustainability-oriented bond issue with clear additional statements about the commitment to deploy funds towards projects and activities in the Green Bond Principles use of proceeds categories* (HSBC and BNP Paribas pp. 5, 2018).

A distinction BNP Paribas and HSBC (2018) points out is that Bloomberg includes a green classification if the issuer itself classifies its bond as green. In accordance with Zerbib (2019), Karpf and Mandel (2018) and Baker et al. (2018), we use Bloomberg's framework to define the "greenness" of their bonds.

2.2. Data Collection

In order to collect our data, we use Bloomberg. We collect a sample (i.e., population) of SEK denominated bonds in the real estate industry issued from 2016-01-01 to 2020-11-20. This results in a sample of 472 bonds, 311 brown and 161 green bonds. The characteristics we retain are the bond's identification number (ISIN), green label, coupon rate, coupon type, issuer, maturity date, amount outstanding, maturity type, credit ratings from Moody and S&P and sector.

Following Zerbib (2019), we choose to remove bonds that do not have a fixed coupon. The reason for this is to make the bond's share the same bond characteristics for comparing reasons. The filtration process resulted in a removal of 303 brown bonds (296 floatings, 5 defaulted, 1 pay-in-kind and 1 zero-coupon) and 101 green bonds, all with a floating coupon. Our sample is now reduced to a number of 169 bonds.

We also exclude bonds that do not have the maturity type of *at-maturity*, resulting in a removal of 26 brown bonds. This leaves our final sample with a total of 141 bonds. Finally, we exclude the dates where the Z-spread is not available, which leaves us with 6548 included observations.

As of credit rating, we use S&P's and Moody's credit rating of the issuer. We sort the ratings into four different categories: B/BB, BBB, A and AA. For the companies where ratings from S&P and Moody's are unavailable, we use Bloomberg's credit rating and compare it with S&P and European Banking Authority's (2006) credit table to retain an estimate in the S&P equivalent scale (see Appendix).

Using the bond's ISIN number, we collect the Z-spread, ask price, bid price and mid-price of every bond on Bloomberg. The variables are measured daily and expressed in basis points. Mid-price is calculated by adding the best bid price with the best ask price and dividing it by 2. Furthermore, the bid-ask spread is calculated by subtracting the bid price from the asking price, dividing it with the mid-price in accordance with Fong, Holden and Trzcinka (2017), and after that converting it to basis points to make it easier to interpret.

$$(2)\ BA_{i,t} = (\frac{ask_{i,t} - bid_{i,t}}{mid_{i,t}}) * 10000$$

2.3. Matching Method and Matching Process

In accordance with Zerbib (2019), Gianfrate and Peri (2019), Hachenberg and Schiereck (2018), Nanayakkara and Colombage (2019), Hyun et al. (2020) and Bour (2019), we choose to investigate the green bond premium using a matching method. The first step of the method is to create matching pairs between green and brown bonds. In order to compare the yield spreads of the bonds, their characteristics should be identical, except the bid-ask-spread. Due to the nature of the bond market, bonds rarely have the same characteristics and therefore not the same yield, which is the reason behind the creation of synthetic bonds (SB), which will be explained later in this section.

We use similar matching criteria as Zerbib (2019) and partly Bachelet et al. (2019), including a two-step verification. Firstly, we exclude bonds that do not have the same: currency, coupon type, bond structure seniority, issuer and collateral, which we choose as our sample's delimitation. Secondly, we construct pairs based on the fact that neither of the brown bonds has a maturity nor issuance date two years outside of the green bond, as well as controlling for the issue amount to neither be 0,25 nor 4 times the size of green bonds issue amount. Additionally, we reuse two brown bonds in two different synthetic bonds. Reusement of bonds should not affect the yield spread differences in a particular direction since all bonds are matched following the same criteria.

When the bonds are filtered against the matching criteria, we create the synthetic bond by converging two bond yield spreads, controlled for maturity, to one. The synthetic bond yield spread is constructed by using Zerbib's (2019) interpolating method, which adjusts the two brown bonds' yields linearly to match the green bond's maturity. Thus, the triplet (one green plus two brown) shares the same maturity.

$$(3)\ Z\text{–}spread_{i,t}^{SB} = \frac{Z\text{–}spread_{i,t}^{BB2} - Z\text{–}spread_{i,t}^{BB1}}{Maturity_{BB2} - Maturity_{BB1}} * (Maturity_{GB} - Maturity_{BB1}) + Z\text{–}spread_{i,t}^{BB1}$$

To control for liquidity, we adjust the brown bonds' bid-ask spread for maturity to create a liquidity proxy for the synthetic bonds in accordance with Zerbib (2019). First, we calculate the difference between the bonds' maturities:

$$(4)\ d_1 = Maturity_{GB} - Maturity_{BB1}$$

$$(5)\ d_2 = Maturity_{GB} - Maturity_{BB2}$$

Equation (4) and (5) is thereafter integrated into the equation (6) to estimate the synthetic bond's bid-ask spread:

$$(6)\ BA_{i,t}^{SB} = (\frac{d_1}{d_2+d_1}) * BA_{i,t}^{BB2} + (\frac{d_2}{d_2+d_1}) * BA_{i,t}^{BB1}$$

After calculating the synthetic bonds' bid-ask spread and yield spread, we compute the difference between the green bond and synthetic bond with respect to the yield spread and the liquidity, as shown in equation (7) and (8).

$$(7)\ Z\text{–}spread\ Difference_{i,t} = Z\text{–}spread_{i,t}^{GB} - Z\text{–}spread_{i,t}^{SB}$$

$$(8)\ \Delta BA_{i,t} = BA_{i,t}^{GB} - BA_{i,t}^{SB}$$

As described above, we match our triplets to the same conditions as Zerbib (2019) used. Furthermore, many companies either issue many brown bonds and few green bonds and vice versa. This narrows down the sample to 9 triplets whereof 6 triplets are AA-rated, 2 triplets are A-rated and 1 triplet is BBB-rated. Ultimately this results in 6548 observations. Compared to other articles using the same method (see (Zerbib, 2019) & (Bachelet et al., 2019)), this seems like a small sample of triplets. However, 6548 observations should still be enough to get accurate results in the sense of sample-size; the biases in the data are further discussed under the selection bias topic.

2.4. Selection Bias

Our sample is small in relation to the number of triplets Zerbib (2019) had and in general to previous studies, but since we include a longer time period, our sample still consists of 6523 observations. Thus, as every day is unique in the sense of the difference between the yield spreads, a longer time period should give each comparison a more reliable green bond premium.

Moreover, the limited amount of bond triplets and SEK denominated green junk bonds, i.e., bonds with a lower rating than BBB, results in a sample where only companies with a rating of BBB, A and AA are included. Zerbib (2019) finds that the green bond premium is larger for junk bonds. As we only include investment-grade bonds, i.e., bonds with a BBB rating or higher, our result could be biased in the sense of a smaller green bond premium. However, the limited amount of green junk bonds concerns previous studies as well, where the vast majority of the bonds are investment grade in the studies conducted by Zerbib (2019) and Bachelet et al. (2019), to mention a few.

3. Empirical Methodology and Results

3.1. Descriptive Statistics

Table 2: Descriptive statistics
Statistics of various variables of the bonds included in the regression. Where the Average Z-spread of BB1 and BB2 are the two bonds combined statistics. The liquidity difference between GB and SB is relatively large in the minimum and maximum value. This is related to spring 2020, where the COVID-19 crises caused damage to the bond market in the form of a highly fluctuating market. Z-spread Diff is the difference between the green bonds Z-spread and the interpolated brown bonds Z-spreads. Bid-ask spread Diff is determined by the difference between green bonds bid-ask spread and the interpolated brown bonds bid-ask spread.

	Sample					
Variables	*Min.*	*1st quart.*	*Median*	*Mean*	*3rd quart.*	*Max.*
Z-spread Diff, (bp)	-35,48	-0,77	-0,07	-0,01	0,74	53,95
Z-spread GB, (bp)	17,71	42,55	55,88	63,41	78,11	175,56
Z-spread SB, (bp)	18,00	42,45	56,10	63,42	78,06	193,52
Z-spread BB1, (bp)	14,91	31,77	45,81	57,19	68,82	192,59
Z-spread BB2, (bp)	14,46	34,58	48,22	56,72	70,09	183,91
Bid-ask spread Diff, ΔBA *(bp)*	-149,28	0,44	5,51	5,85	9,56	158,71
Bid-ask spread GB, BA^{GB} *(bp)*	7,32	25,35	33,17	35,23	38,83	300,84
Bid-ask spread BB1, BA^{BB1} *(bp)*	1,40	17,69	25,06	27,79	32,88	204,26
Bid-ask spread BB2, BA^{BB2} *(bp)*	2,0	18,77	25,85	28,33	34,67	218,56
Days-to-maturity total	862	1126	1219	1264	1448	1953
Days-to-maturity GB	1119	1133	1351	1417	1679	1953
Days-to-maturity BB1	862	1002	1191	1178	1283	1451
Days-to-maturity BB2	889	1126	1219	1198	1366	1479
Issued amount total (mil.)	100	200	450	461	600	1000
Issued amount GB (mil.)	150	200	390	452	275	1000
Issued amount BB1 (mil.)	200	376	550	552	445	885
Issued amount BB2 (mil.)	100	100	376	378	100	850

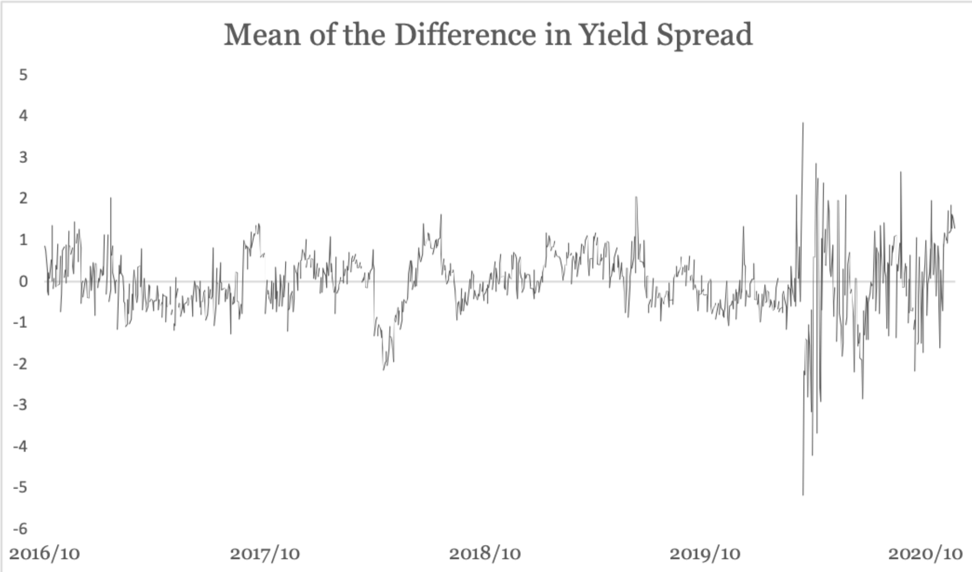

Figure 4. *The green bond premium (measured in bps) illustrated over time by the mean of the yield spread difference between the synthetic and green bonds.*

Table 2 shows that the average yield spread between green and synthetic bonds is -0,1bps. However, the average in the brown bonds samples 1 and 2 is considerably smaller than the average in the green bonds, yet one must bear in mind that brown bonds are not interpolated nor extrapolated. Observing figure 4, it is difficult to notice any difference in the yield spread.

Table 2 further shows that the average bid-ask spread is higher for the green bonds, i.e., the green bonds are traded less frequently than the brown bonds.

3.2. Preliminary Results

Zerbib (2019) and Bour (2019) suffered from heteroskedastic residuals. Hence, as there is a possibility of heteroskedasticity, we run a test for heteroskedasticity in time. If heteroskedasticity is present, the ordinary least square estimator would be inefficient.

Table 3: Test for Heteroskedasticity

Null hypothesis: Residuals are homoskedastic.

Breusch-Pagan test against heteroskedasticity		
	Value	*Prob.*
Entire Period	3619,40	0,00***
Pre-COVID-19 Period	2586,06	0,00***
Early period	1327,41	0,00***

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

The tests from **Table 3** implies that the residuals are heteroskedastic for all regressions since we reject the null hypothesis.

Zerbib (2017, 2019) had serially correlated standard error, which frequently occurs in time-series data. To test whether our regression suffers from serial correlation or not, we performed a Woolridge test.

Table 4: Test for Serial Correlation

Null hypothesis: No serial correlation.

Wooldridge test	
	Prob.
Entire Period	0,00***
Pre-COVID-19 Period	0,00***
Early period	0,00***

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

Observing the results in **Table 4**, we can confirm that our sample suffers from serial correlation. Hence, our error terms are correlated.

Non-stationary data, i.e., a unit root, is common in time-series cross-sectional data. Observing figure 3, there is no obvious unit root in the dependent variable. To certify that our data is stationary, we perform various tests for a unit root's potential presence.

Table 5: Test for Unit Root

Null hypothesis for all tests: Unit root. Tests for a unit root in the explanatory variable, i.e., the Z-spread difference between synthetic and green bonds in the Entire period (hence the entire sample).

Panel unit root test		
	Statistics	*Prob.*
*Levin, Lin & Chu t**	-13,21	0,00***
Im. Pesaran and Shin W-stat	-19,38	0,00***
ADF - Fisher Chi-square	411,17	0,00***
PP - Fisher Chi-square	1399,86	0,00***

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

As we can reject the null hypothesis in **Table 5**, we can conclude that the dependent variable is stationary.

3.3. Estimated results

When we have compiled the data for triplets as panel data, we run a cross-sectional fixed effects panel regression, including 6548 panel observations and 9 cross-sections. Referring to equation (9), the yield spread difference is the dependent variable and liquidity difference is the explanatory variable. Panel regression with fixed effects is employed by Zerbib (2019) and Bachelet et al. (2019), to mention a few. By including fixed effects for the bonds, the difference between each synthetic and green bond is captured and interpreted as the green bond premium. We will include three regressions for three different time-periods: Early period, Pre-COVID-19 period and Entire period.

As we have serial correlation and timewise heteroskedasticity, we run a fixed effect generalized least squares estimator in accordance with Zerbib (2017, 2019) and Hyun et al. (2020). We allow the error covariance structure in bonds to be unconditional to account for serial correlation and timewise heteroskedasticity.

$$(9)\ Z\text{–}Spread\ Difference_{i,t} = \alpha_i + \beta \Delta BA_{i,t} + \varepsilon_{i,t}$$

Table 6: Fixed Effect Generalized Least Square Estimators
The results from equation (9) are presented below. $\Delta BA_{i,t}$ *origin from equation (8) and* $Z\text{–}Spread\ Difference_{i,t}$ *origin from equation (7). Standard errors are reported in parenthesis.*

Dependent variable: Z-spread Difference Within estimation					
	Coefficient	*z-value*	*Prob.*	*R-squared*	*Obs.*
ΔBA *(Entire Period)*	-0,017 (0.004)	-3,99	0,00 ***	0,057	6548
ΔBA *(Pre-COVID-19 Period)*	0,040 (0,005)	8,54	0.00 ***	0,086	4604
ΔBA *(Early Period)*	0,093 (0,015)	56,79	0,00 ***	0,062	2057

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

By analyzing **Table 6**, we observe a decrease in liquidity difference over time, indicating that the green bonds' liquidity relative to the brown bonds' liquidity has increased, which can be interpreted as the brown bonds surpassing green bonds regarding liquidity risk.

The fixed effects of the regressions in **Table 6** are presented in **Table 7**. The mean is interpreted as the green bond premium as it is the average of 9 bond triplets, respectively 8 bond triplets for the Early period.

Table 7: Green Bond Premiums
The green bond premium for all three periods.

Green Bond Premium: $\widehat{\alpha}_i$						
	Min.	*1st Quartile*	*Median*	*Mean*	*3rd Quartile*	*Max*
Entire Period	-0,77	-0,42	0,02	0,16	0,41	1,85
Pre-COVID-19 Period	-0,71	-0,42	-0,17	-0,13	0,21	0,37
Early Period	-1,65	-0,97	-0,70	-0,60	-0,41	1,05

We choose to perform a Wilcoxon signed-rank test in order to determine whether the green bond premium is significant or not. Furthermore, we perform a Wilcoxon signed-rank test for small values (Körner, 2015) since we only have 9 fixed effects. Hence, we can not assume a normal distribution due to the small sample of fixed effects. Zerbib (2019) also performed this test, although he computed the test assuming a normal distribution since his observations were large enough.

Firstly, we perform the test by ranking the absolute values of the fixed effects, i.e., green bond premiums. Secondly, we sum the rank numbers of the initially negative and positive values separately. Finally, the smallest absolute value of these sums is the number observed in the test. Furthermore, we use the critical value, found in a Wilcoxon signed-rank test table, for a specific number of observations to determine each regression's significance; the test provides an interval for the p-value. The result is presented below.

Table 8: Wilcoxon Signed-rank Test

Null hypothesis: The difference between the green and synthetic bonds is zero. For the Early period (2016-10-13 - 2018-12-31) the significance is between 0,05 and 0,1.

	Wilcoxon signed-rank test
	Prob.
Entire Period	*>0,10*
Pre-COVID-19 Period	*>0,10*
Early period	*0,05-0,10**

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

As we only have 9 bond triplets, 8 bond triplets in the Early period, we can not run a regression with the fixed effects as dependent variable on the green bond premium determinants. Instead, we choose to solely observe the mean difference in bond triplets with specific credit ratings. Furthermore, we perform a Wilcoxon signed-rank test as described above to determine the mean values' significance.

Table 9: Credit Ratings On the Green Bond Premium

There are not enough bond triplets of rating BBB and A to perform a Wilcoxon signed-rank test.

Mean of green bond premiums			
	BBB	*A*	*AA*
Entire Period	*-0,42*	*1,38*	*-0,17*
Pre-COVID-19 Period	*0,34*	*0,29*	*-0,36***
Early period	*1,05*	*-1,65*	*-0,70***

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

4. Discussion and Analysis of Results

By analyzing the Early period in **Table 7** and **Table 8**, we can observe a 10 percent significantly negative green bond premium of approximately 0,6bps, meaning that green bonds are more expensive than brown for investors. The result is coherent with Zerbib (2019), Hyun et al. (2020), Bour (2019), Nanayakkara et al. (2018), Gianfrate et al. (2019), Preclaw and Bakshi (2015), Baker et al. (2018) and Karpf et al. (2018), who reported negative green bond premiums overall. However, their reported negative green bond premiums are substantially larger than ours. While the Early period is significantly negative, the Pre-COVID-19 period is insignificantly negative and the Entire period insignificantly positive – our results indicate a decreasing green bond premium over time. Although our delimitation separates us from previous studies, we still conduct the same method, yet report a considerably smaller green bond premium for all periods than the aforementioned reports. An explanation for the difference in result could be argued as a fallout of our delimitation to the SEK denominated real estate bond market.

In addition to the overall green bond premium results, we find a 5% significant negative green bond premium in AA-rated bonds for the Early period and Pre-COVID-19 period (**Table 9**). Observing the other ratings, our sample does not consist of enough bonds to test for significance. Further analyzing the results, it is beyond comparison to determine any difference regarding the credit rating's impact on the green bond premium. Nevertheless, one can observe that the green bond premium for AA-rated bonds is smaller than the overall green bond premium for all periods.

Although our delimitation affects the green bond premium, other factors could also be critical for the premium. Elementary economy models could explain the fact that the green bond premium is negative for the shortest period and positive for the most extended period. The number of issued green bonds in the real estate sector has increased rapidly over the past years, more precisely, approximately 42% from 2018 to 2019 (Bloomberg, 2020). Hence, for the green bond premium to remain negative, as in the Early period, one could argue it would be required that the demand for green bonds increase at the same pace as the supply. Therefore, the insignificant positive green bond premium of 0,16bps in the Entire period could be explained by a faster-growing supply than demand for green bonds (see **Table 8**). On the contrary, Pettersson (phone interview, December 8, 2020) said that it is hard to tell whether the supply has increased more than the demand, yet he believes that the demand has increased at least as much as the supply. However, it is essential to bear in mind that the green bond premium from the Entire period is not significantly different from zero.

Further analyzing the Entire period, a potential explanation for the positive green bond premium could be found in the irregular market movement during spring 2020, i.e., the COVID-19 crisis. Bid-ask spreads extreme movement impacted the yield spread (The Riksbank, 2020), resulting in an unusual increase. Similar market behavior could be observed during the financial crisis in 2008, where the liquidity decrease had a significant effect on yield spreads (Friewalda et al., 2011). We did not find any studies indicating that green and brown bonds expects to behave differently during a liquidity crisis, yet our results indicate a different relationship between the yield spread and the bid-ask spread before and after the COVID-19 crisis. Observing **Table 6**, the liquidity estimators show a positive relative bid-ask spread in the Pre-COVID-19 period and a negative in the Entire period. The conversion from a positive to a negative bid-ask spread estimator, relative to the yield spread, should be further investigated as it could explain how investors' preferences change during liquidity crises. Regardless of whether the green bond premium in the Entire period is affected by the COVID-19 crisis or not, the result from the Pre-COVID-19 period was also insignificantly different from zero. Thus, we can not exclude the possibility of a conversion to a non-existing green bond premium in 2020.

A supporting theory for a non-existing green bond premium is the *Efficient market hypothesis* (EMH). Considering the theory in our context, one could argue that the yield spread between green and brown bonds should be absent, as bonds issued by the same company are exposed to the self-same risk. Nevertheless, it remains hard to determine to what extent the theory can be applied to our results since the bond characteristics are approximately the same, but not exactly the same. Referring to Pettersson (phone interview, December 8, 2020), he stated that to achieve a fully reliable result, one needs to study green and a brown bond with identical specifications.

Further discussing Pettersson's statement, our method does not account for issue amounts, which could be biased as the size of the issue amount could affect the yield spread. Thus, **Table 1** shows that the mean of the green bonds issue amount is almost precisely between the mean of brown bonds 1 and brown bonds 2. Additionally, the difference in the issue amount is controlled by bid-ask spread as a liquidity proxy. Another potential bias could be the inaccuracy of the interpolation of the yield spreads. However, the method is standard in financial theory and should not affect the result in a specific direction.

5. Conclusion

The emphasis of a shift in allocation regarding carbon-intensive investments to LCCR investments has made the green bond market necessary to reach the Paris agreement's climate goals. With Sweden being ranked fourth in most issued green bonds and Vasakronan positioning as the second to the most frequent issuer globally (Almeida, 2019), it has made the Swedish bond market an appropriate field to study.

In the field of green bond yield discrepancies, our paper extends the body of literature by contributing with an analysis on an unexplored delimitation - the Swedish secondary market for SEK denominated real estate bonds. We constitute a study of 9 bond comparisons and 6548 observations from October 2016 to November 2020, while accounting for the COVID-19 crisis' impact by analyzing two time intervals before the crisis affected the market. Our method consists of a matching method and fixed effects generalized least square estimator, in accordance with Zerbib (2017, 2019) and Hyun et al. (2020). We employ a Z-spread and control for liquidity with a bid-ask spread to measure the green bond premium.

The result suggests a significant negative green bond premium on 0,6bps in the Early period and insignificant results in the Pre-COVID-19 period and Entire period. Therefore we can no longer confirm a green bond premium in the secondary real estate market, aligning our results with the EMH. However, further studies need to be conducted to assert whether a green bond premium is present in the real estate sector or not. Potentially a comparison between a green and a brown bond with identical bond characteristics is necessary. Whether the COVID-19 crisis affected the significance of the result or not is difficult to determine. No previous literature suggested a different liquidity behavior from green and brown bonds during a financial crisis, an interesting topic for future studies in this field of study.

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Appendix

Table 10: Credit Ratings

S&P Equivalent	*Moody's Long Term*	*S&P Long Term*	*Fitch*	*Bloomberg*	Category
AAA	Aaa	AAA	AAA	IG1	*Investment Grade*
AA	Aa1, Aa2, Aa3	AA+, AA, AA-	AA+, AA, AA-	IG2, IG3, IG4	
A	A1, A2, A3	A+, A, A-	A+, A, A-	IG5, IG6, IG7	
BBB	Baa1, Baa2, Baa3	BBB+, BBB, BBB-	BBB+, BBB, BBB-	IG8, IG9, IG10	
BB	Ba1, Ba2, Ba3	BB+, BB, BB-	BB+, BB, BB-	HY1, HY2, HY3	*Junk Bonds*
B	B1, B2, B3 or lower	B+, B, B- or lower	B+, B, B- or lower	HY4, HY5, HY6 or lower	

Table 11: Matching Criteria

Characteristics	**Matching Criteria**
Issuance date	Maximum 2 years earlier or 2 years later than the corresponding green bond's issuance date
Issue amount	Less than 4 times and greater than 0.25 of the corresponding green bond's issued amount
Maturity date	Maximum 2 years earlier or 2 years later than the corresponding green bond's maturity date
Coupon rate	Maximum 2% higher or 2% lower than the corresponding green bond's coupon rate
Rating	Same
Issuer	Same
Coupon type	Same
Currency	Same
Seniority	Same