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# The Green Bond Yield Dilemma

A Quantitative Study of Bond Pricing and Liquidity in the Secondary Market in Sweden

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ABSTRACT

This paper examines if green bonds are priced differently than conventional bonds in the Swedish secondary market. We further explore if there is a difference in the liquidity effect on yield between the two bond types. Looking at transaction data for 32 green bonds and 303 conventional bonds for the period 2013-2017 and controlling for bond yield affecting factors, we find that green bonds exhibit lower yield than conventional bonds. The difference is largest in 2013-2014 and decreases over time. For the whole period, the yield difference is quantified to 12.9 basis points. We do not find robust evidence for a green liquidity effect on yield. Our results have implications for national policymaking and reveal a dilemma that investors have to address. This highlights the need for future research in the yet limited field of green bond pricing.

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# I. Introduction

The future calls for sustainable investments and green bonds play a vital role in fulfilling this. Global climate leaders have identified that the world needs USD 1tn invested in green bonds by 2020 to achieve a low carbon transition and a climate-resilient world (Nicol et al., 2018). A green bond is a bond from which the funds raised must be targeted to environmentally sustainable projects (International Capital Markets Association (ICMA), 2017a). We compare the former with conventional bonds, hereafter referred to as *brown* bonds.

The green bond market has evolved rapidly since its inception. The first green bond in the world was issued in 2007 (Kochetygova and Januhari (S&P Dow Jones Indices), 2014) and the first SEK denominated bond was issued in 2013 (CBI, 2018a). Sustainable investment policies following the Paris agreement[1] have vigorously increased the demand for green investments. The total issued amount of green bonds grew by an annual rate of more than 92% (CBI, 2017a) to USD 87.2bn in 2016[2] and by 78% to USD 155.5bn in 2017 (CBI, 2018b). The substantial amount issued and the double digit year-on-year growth demonstrate the magnitude of the market's ongoing development.

Since investors have become increasingly committed to invest in green bonds, anecdotal evidence suggest a *greenium*: a price difference arising between green and brown bond yield curves in the primary market[3] (CBI, 2018c). The greenium indicates that green bonds are more expensive than the brown equivalents, which has implications for investors, issuers and policymakers aiming to bridge the climate target investment gap. It is therefore relevant to see if such a price discrepancy exists in the more dynamic secondary market.

Sweden is an important contributor to the development of the green bond market and a role model in terms of issuance size[4], diversification of issuers and green label integrity (CBI, 2018a). In January 2018, the Swedish government presented an official inquiry suggesting ways to further develop the green bond market (Swedish Government Official Reports, 2017). The

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[1] The Paris agreement referring to the Climate Summit in Paris 2015 where 188 parties from different nations aligned on goals to keep the global temperature rise below 2 degrees Celsius. The green bond market was acknowledged as an important area of development to achieve this (CBI, 2017a)

[2] Updated numbers from 81.6bn to 87.2bn (CBI, 2018b). 92% growth (CBI, 2017c) based on old number of 81.6bn

[3] *Primary market* referring to transactions at issuance, when investors buy directly from the issuer. The *secondary market* is where bonds can be traded after issuance until maturity

[4] Issuance size in terms of green bond issuance relative to market size (CBI, 2018a)

aftermath has been a political debate concerning the government's proposed methods to achieve this. The Swedish National Debt Office has officially opposed the government's proposal of a green sovereign bond (Swedish National Debt Office, 2018), primarily based on the difficulties related to fitting such funding into the current sovereign debt. Kommuninvest, a national debt office representing 288 municipalities and local governments in Sweden, supports the government's initiative, but disagrees with the proposed green bond subsidies (Kommuninvest, 2018a). The political debate highlights the need for further research on green bonds. Based on this, in combination with Sweden being a pioneer in the green bond market, it is of both global and local relevance to conduct this study in Sweden.

Recalling the urgent need for sustainable investments, the rapid evolvement of the green bond market and Sweden as a relevant country to study, the aim of this paper is to bring further understanding to the yet limited field of how green bonds are priced in the secondary market. Going one step further, we explore if liquidity has an impact on green bond pricing. We choose to examine liquidity since it is the most recognized non-default factor in literature to explain yield spreads, see for example Longstaff et al. (2005) and Chen et al. (2007). It is also a yield determinant that captures buyers' and the sellers' behavior in the market. The research question is phrased as the following:

**Is there a yield difference between green and brown bonds in the secondary market for SEK denominated bonds? Can a green bond liquidity effect explain such a yield discrepancy?**

*Negative yield premium, negative premium* or *negative yield spread* will hereafter refer to a negative difference between green bond yield and brown bond yield. The negative premium is in other words the yield that the investor would sacrifice when buying a green bond instead of the brown counterparty. *Positive premium* is the other way around.

The remaining part of our research paper is structured as the following. The second part will review relevant literature constituting the background and the theoretical framework to the paper. It also includes insights from conducted pre-study interviews. The third part explains the data set and the method used. The fourth part presents the results and the fifth part includes discussion and critical reflections of the results. The final part of the paper is a brief conclusion followed by the reference list.

# II. Background

## 2.1 Review of Literature and Qualitative Pre-study

*2.1.1 The Green Bond Premium*

Previous academic research conducted on green bonds is limited and the market is still in a growth phase. Thus, there are only a few studies addressing the topic based on data recent enough to explain the current reality of the green bond market. We interpret previous research findings with some caution due to the lacking number of studies in combination with the fact that these studies have been conducted on markets other than the Swedish market.

As described in the previous section, the Climate Bonds Initiative (2018c) has recognized a price discrepancy in the primary market, also referred to as *greenium*. However, the study is based on scarce empirical data and should be interpreted with caution. There are two studies by Karpf and Mandel (2017 and 2018) as well as one of Zerbib (2017), that investigate green bond pricing in the secondary market in the US and globally respectively, with data until 2016. There are not yet any equivalent research papers studying the Swedish market.

Karpf and Mandel (2017) study green bond pricing in the US municipal market. They find that green bonds historically have been penalized due to the fact that they are green, meaning that they have traded at higher yields than what is expected by their characteristics in comparison to brown bonds. Revising the same topic again with the same method but with more recent data, Karpf and Mandel (2018) find a shifting trend from 2015 and forward. With data from 2010 to 2016 they identify that with all other things being equal, investors have historically required a higher yield (positive yield premium) for green bonds than brown bonds. From 2015, they find that green bonds have had lower yield (negative yield premium) than the equivalent set of brown bonds.

Zerbib (2017) finds a significant negative green premium when using a matching method for 135 investment grade senior bullet bonds issued in 18 different currencies worldwide with transaction data from 2012 to 2016. Zerbib finds this result to be consistent over time when focusing on EUR and USD bonds solely, but recognizes that including the larger number of currencies limits the accuracy of the estimation. The average green bond yield found for Sweden is 0.21%, which should not to be confused with *yield premium*, but no country-specific measure of a green bond premium is presented. Zerbib controls for liquidity effects pre-regression and uses zero trading days and bid-ask spread as liquidity proxies.

The study highlights the need to control for dynamic effects such as currency and liquidity when trying to isolate and explain a potential price difference for green bonds.

### *2.1.2 The Swedish Green Bond Market*

Sweden is the seventh largest source of green bonds in the world, and also the first issuer of a corporate green bond, issued by Vasakronan in 2013. SEK denominated bonds account for 12% of the total green bond volume globally (SEB, 2018). Swedish municipalities have taken the lead of green bond issuance and are accounting for 41% of the European local government issuance, with the largest contributor in the official sector being Kommuninvest. Investors in the SEK green bond market are mostly larger institutional investors committed, and sometimes on dictated mandate, to invest green (Swedish Government Official Reports, 2017). The AP funds (i.e. the Swedish national pension funds) have invested more than SEK 25bn in green bonds (*ibid*) In Kommuninvest's last issuance of SEK 3bn, asset managers represented 51%, pension funds 29% and insurance companies 17% (Kommuninvest, 2018b).

Interviews with stakeholders in the Swedish bond market; Kommuninvest[5], Vasakronan[6], Danske Bank[7] and a Finance Professor at the Stockholm School of Economics[8], demonstrate an overall expectation of a negative green yield premium in the secondary SEK bond market. Mattias Bokenblom and Erik Törnblom from Kommuninvest (phone interview, March 20, 2018) emphasize that green bonds issued by Swedish municipalities are oversubscribed at issuance. They experience that the negative green premium in the primary market (i.e. *greenium*), mainly caused by a strong demand for green investments among institutional investors, indicates a similar premium in the secondary market. Thomas Nystedt at Vasakronan (phone interview, March 16, 2018) confirms the view that the negative green bond premium might exist on the secondary market. Nystedt further explains that the green bond premium infers a decreased financing cost for issuers and that this is one reason for Vasakronan's active issuance of green

[5] Kommunnvest is a cooperative and non-profit debt office targeting the need to provide high quality debt (AAA+) to local governments and municipalities. Kommuninvest represents 288 municipalities and is the largest green bond contributor in the official sector. We interviewed with Mattias Bokenblom, Head of Research and Education at Kommuninvest and Erik Törnblom, Analyst at Kommuninvest

[6] Vasakronan is the largest corporate issuer in Sweden and the first corporate issuer in the world. We interviewed with Thomas Nystedt, CFO at Vasakronan

[7] We interviewed with Lars Mac Key, responsible for Sustainable Products at DCM Origination, Danske Bank

[8] We interviewed with Bo Becker, Professor at Stockholm School of Economics and Program Director at Mistra Center for Sustainable Finance. Becker is currently studying the green bond market

bonds. Lars Mac Key at Danske Bank (phone interview, May 4, 2018) argues that there might be a negative green premium at issuance on an aggregate level, but that the premium seems to decrease after issuance on the secondary market.

As of liquidity for green bonds in Sweden, the answers are less unanimous. Nystedt, Bokenblom and Törnblom propose that the liquidity might be better for green bonds in regards to that they are "easier to sell". Professor Bo Becker (personal interview, April 24, 2018) and Lars Mac Key argue that the SEK bond market is less liquid than markets such as the EUR and USD and that this makes the relationship between liquidity and price less direct. Another mechanism that could affect liquidity, mentioned by Bokenblom, Mac Key and Professor Becker, is that investors more often tend to have a buy-and-hold strategy for green bonds than for brown bonds.

## 2.2 Theoretical Framework

### *2.2.1 Yield and Asset Swap Spread*

The yield to maturity is a common measure when comparing bond pricing, as it accounts for the current market price, the face value, the future coupon payments and the time to maturity. However, the price of a bond is correlated with the prevailing risk-free interest rate (Berk and DeMarzo, 2014). To account for changes in the risk-free interest rate when studying bond yields over time, we choose to use the asset swap spread, hereafter called *ASW*. Another important benefit of the ASW compared to yield to maturity is that it enables inclusion of floating bonds, as the ASW effectively translates a fixed coupon into a floating rate (Thomson Reuters, 2016).

An asset swap is an agreement between a bond holder and a third party investor, called swap investor. In the agreement, the swap investor receives the fixed coupon payments from the bond in exchange for paying a floating rate based on LIBOR plus minus the ASW to the bond holder, see **Figure 1**. The ASW is therefore the component that balances the values of the fixed and floating streams in the interest rate swap (Chaplin, 2015). ASW takes into account the current market price, the face value, the future coupon payments, the time to maturity and *the risk-free interest rate* (Thomson Reuters, 2016). The ASW can therefore be seen as a measure of yield to maturity adjusted for the risk-free interest rate. The method using ASW follows the approach used by Zaghini (2014) and Zaghini and Pianeselli (2014). It is also analogous to the method used by Longstaff et al. (2005), where they use CDS[9] and average yield spread over the indicated risk-free curve as measures for bond yield spreads.

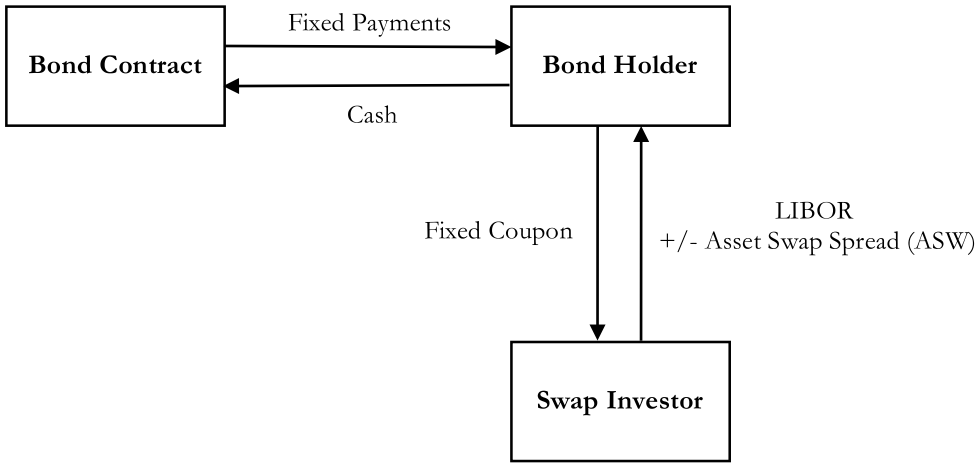


**Figure 1**: Figure showing the ASW transaction flow. The value of the ASW is the credit spread above or below LIBOR

The market price of a bond should reflect the conditions of the agreement that the bond investors enters. Besides the variables accounted for in the ASW, theory expects the price to be correlated with a number of explanatory factors. These factors and their impact are presented below.

*2.2.2 Credit Risk*

Credit risk is known to positively affect bond yield, meaning that a higher yield is required for a higher credit risk profile. This relationship was investigated by Yawitz et al. (1985), further confirmed by Longstaff et al. (2005) and acknowledged by contemporary literature such as Berk and DeMarzo (2014), Elton et al. (2001), Chen et al. (2007) and Karpf and Mandel (2017 and 2018). We use issuer credit rating from Moody's, S&P and Fitch to measure credit risk, which is the most commonly used method in literature. Whilst Chen et al. (2007), Longstaff et al. (2005) and Zerbib (2017) split the rating scale into five or six categories (consisting of the S&P equivalent steps; AAA, AA, A, BBB and BB), Karpf and Mandel (2017 and 2018) split it into two categories (representing high and low credit rating).

[9] Credit Default Swap (Chaplin, 2015)

*2.2.3 Liquidity and Bid-Ask Spread*

Liquidity is documented to have an impact on bond pricing (Chen et al. (2007), Fontaine and Garcia (2012), Amihud et al. (2005), Amihud and Mendelson (1986)). Chen et al. (2007) use bid-ask spread, LOT and percentage zeros as proxies for liquidity and find a significant correlation between liquidity and yield spreads. They acknowledge the bid-ask spread as the most utilized liquidity proxy in literature.

The bid-ask spread is also used by Amihud and Mendelson (1986), Brandt and Kavajecz (2004) and Dick-Nielsen et al. (2012) and Zerbib (2017) to mention a few. Amihud and Mendelson (1986) motivate the use of bid-ask spread as a liquidity proxy by explaining how the current bid and ask price respectively includes a premium for the buyer or seller that compensates the trader for a transaction today compared to waiting for a transaction later on. If both parties are willing to buy and sell today, the prices will be closer to each other and consequently the bid-ask spread will be lower. If there is a risk that the bond holder will not be able to sell the bond for an acceptable price when she plans to, this risk should be priced into the bond yield as a compensation.

Karpf and Mandel (2017 and 2018) use the frequency of transactions and the transaction turnover as proxy for liquidity, a method that can be interpreted as a complement when studying liquidity. Due to resource constraints, we are not able to access data that measure trading frequency or transaction volume. A similar problem is recognized for Longstaff et al. (2005). The number of relevant studies confirming a liquidity effect on bond yield is the basis for our choice to investigate such an effect in the green bond pricing puzzle. We choose to use the bid-ask spread as the liquidity proxy for our study since this is the most recognized and utilized method among the research papers outlined above.

*2.2.4 Time to Maturity*

We use days to maturity to account for the time to maturity effect. A longer time to maturity correlates with a higher ASW, since a longer time horizon implies a higher interest rate risk (Berk and DeMarzo, 2014). Note that the time dimension accounted for in ASW only represents the time value of money, while this measure represents the interest rate risk.

*2.2.5 Type of Bond*

Another factor that needs to be accounted for is the fact that bonds may have different features that affect the required yield. Such features could be that the bond is callable, convertible, asset-backed or has a different coupon type. It is common to exclude bonds with bond features affecting the results, see for example Longstaff et al. (2005), Dick-Nielsen et al. (2012) and Chen et al. (2007). We control for this effect by excluding all bonds that are not plain vanilla, such as callable and convertible bonds. ASW translates fixed and floating coupons into a comparable measure, which enables us to include floating bonds. However, the floating feature in itself is something that the investor may value higher, and it can thus impact the required yield. We control for this by including a dummy variable for floating bonds.

Whether the bond is issued by a corporation or by an official participant (municipality, city or the government) can also have an effect on the yield. The majority of previous literature referred to examines either the corporate (Chen et al. (2007), Longstaff et al. (2005)), the municipal (Karpf and Mandel, 2017 and 2018) or the treasury bond market solely (Brandt et al. (2004), Fontaine and Garcia (2012)). We therefore use precaution and choose to control for a potential "corporate effect", that cannot be explained by the other variables, by including a dummy variable. The reason why we can include bonds from both corporate and official issuers is the absence of tax treatment differences in Sweden, see subsection 2.2.7.

*2.2.6 Amount Outstanding*

Fisher (1959) outlines that with other things being equal, a bond with a smaller principal amount is expected to be traded less frequently, resulting in a thinner market and more uncertain market prices. Smaller principal amounts imply a higher liquidity risk and thus higher yield. Longstaff et al. (2005) use the measure with the same intuition, they interpret that larger principal amounts imply that the bond is more liquid and easier to find in the market. Following the significant coefficient found by Longstaff et al. (2005), one can expect a larger issue amount to give better liquidity and thus a lower yield. Opposing this view, Karpf and Mandel (2017 and 2018) expects a larger principal amount at issuance to be correlated with a higher credit risk resulting in a higher required yield. These effects are contrary and it is not clear which one of them that will outweigh the other, especially since our study is conducted on a different market than the previously mentioned authors'. Yet, it is clear that the principal amount outstanding has explanatory power in literature and needs to be controlled for in the regression. We include this variable measured in SEK millions.

*2.2.7 Taxes and Other Policy Treatment Effects*

Taxes can affect the required yield on a bond (Modigliani Miller, 1958), but this is not an issue when comparing bonds in the Swedish market today (Skatteverket, 2018). The Swedish government has investigated the possibility to put in place inducements to promote further growth of the green bond market (Swedish Government Official Reports, 2017), but the suggestion has, at the time of writing this paper, not had any legislative implications. To exemplify, there are several tax incentives aiming to boost green bond issuance in the US, resulting in not completely comparable market behaviors for green and brown bonds (CBI, 2018d). The fact that we do not need to treat a potential tax effect is a clear benefit, which improves the reliability of our study.

# III. Method

## 3.1 Green Bond Classification

The Green Bond Principles, developed by the International Capital Market Association (ICMA), and the Climate Bonds Standards, developed by the Climate Bonds Initiative[10] (CBI), are the most accepted green classification principles globally. This is recognized by OECD (2017) and the European Commission (Cochu et al., 2016). CBI base their classification on the Green Bond Principles, but the bonds also have to be broadly consistent with their own taxonomy, which outlines further disclosure requirements (ICMA, 2017b).

Zerbib (2017) and Karpf and Mandel (2017 and 2018) use the Bloomberg Green Database for the classification. In addition to being globally recognized, CBI is the green bond database that was launched first and also where the largest number of green bonds are available (ICMA, 2017b). We therefore choose to request data from CBI for green bond classifications.

## 3.2 Field of Study

As earlier presented, we choose to limit our study to SEK denominated bonds issued in Sweden. Compared to Zerbib (2017) who studies green bonds issued in 18 different currencies, our sample of Swedish (SEK) green bonds is significantly smaller. This is a drawback that will be further discussed in section 5.2. However, studying the secondary market of Swedish bonds eliminates currency effect risks and country specific differences such as growth rates, sovereign and municipal debt ratios and tax treatment effects (see subsection 2.2.7). This enables an improved isolation of the "green" effect in our examination.

## 3.3 Data Collection

### *3.3.1 Data Collection Procedure*

The starting point for our data sample is a list of all SEK denominated bonds issued in Sweden between 2013-2017 collected from Thomson Reuters. To find out which bonds that are classified as green, we match the complete list of bonds with a list of all green SEK denominated bonds issued in Sweden for the same period from CBI. The first green bond in our CBI list was issued in 2013 and of comparability reasons we do not include brown bonds issued before 2013.

[10] The Climate Bonds Initiative is an international non-profit organization aiming to mobilize the bond market for climate change

The sample is the complete set of bonds (i.e. *population*) in the market for the given dates (available from Thomson Reuters). There are 87 green and 2926 conventional bonds in the first sample. For all these bonds, daily transaction data and bond characteristics are gathered from Thomson Reuters[11].

We exclude bonds where there is no valid ASW data throughout the whole time period. This decreases the sample to 32 green and 315 brown bonds. We also exclude all callable bonds (less 12 brown). There are no bonds other than plain vanilla (fixed and floating coupon) in the remaining sample. Within the remaining set of 32 green and 303 brown bonds, 1 brown and 3 green bonds have floating coupon rates. These can, as described earlier, be kept in the dataset since we use the ASW and a floating dummy variable. The time period for the transaction data is refined: from 1 October 2013 to 31 December 2017, since the first transaction date for a green bond is 1 October 2013. This does not change the number of bonds in our sample.
To be able to keep as many observations as possible but still use a frequent measure of liquidity, the bid-ask spread is based on a monthly average. A similar approach is used by Chen et al. (2007). The method is also justified by a robustness test, see section 4.3. The ASW is collected in basis points from Thomson Reuters Datastream. The bid-ask spread is based on daily bid and ask closing prices collected from the Datastream and is computed using the same calculation as Brandt and Kavajecz (2004) and expressed in basis points:

$$BidAsk_{Spread} = \frac{Ask_{price} - Bid_{price}}{Mid_{price}} \times 10000$$

The mid price is computed as the midrange of the ask and bid prices. The monthly bid-ask spread average is calculated from the daily data.

We use issuer rating data published by S&P, Moody's and Fitch collected from Thomson Reuters. To keep as many green bonds as possible, we use supplementary data from Bloomberg when rating is not available from Thomson Reuters. The rating steps are translated into a S&P equivalent scale (European Banking Authority, 2006), presented in **Table 7** in Appendix A.

[11] We use the bond identification numbers (*ISIN*) provided by CBI and Thomson Reuters to collect the data: issuer name, issuer rating, principal amount issued in SEK, type of bond, issuer type, issue date and maturity date. We use the bond identification numbers together with all dates within the timespan to collect daily ASW and daily bid and ask prices (closing prices)

*3.3.2 Limitations of Data Collection Procedure*

We recognize a sampling bias arising from the study being conducted only on bonds with recorded ASW data within the time period. It is likely that this influences the sample characteristics, e.g. an increased overall liquidity due to missing transaction data being correlated with illiquid securities. However, there is no reason to believe that such biases would impact green bonds significantly differently than brown bonds and this would therefore not considerably affect the conclusions drawn about a green premium and green liquidity in this study. Lack of data is a common attribute for research papers studying bond markets, which poses challenges that are further discussed in section 5.2.

## 3.4 Description of Variables

The data collection procedure results in the variables presented below.

**ASW**: Daily asset swap spread expressed in basis points for each bond within the dataset. Used as a proxy for the yield.

**BidAsk**: Monthly average of daily computed bid-ask spreads expressed in basis points for each bond within the dataset. Used as a liquidity proxy.

**rating_AAA, rating_AA, rating_A and rating_BB_BBB**: Dummy variables for each credit rating step on a S&P equivalent scale. Due to few observations of BB rating (only 3% of sample, see **Table 2**), steps BBB and BB are combined to create a more equivalent sized group compared to the other rating steps.

**DTM**: Time to maturity expressed in days, computed as maturity date minus the observation date.

**Amount**: Principal amount issued in SEK millions. Used as a proxy for bond size.

**Green**: Dummy variable that enters 1 if green, 0 if conventional. Classification from CBI.

**Corporate**: Dummy variable that enters 1 if the issuer is a corporation, 0 if the issuer is a municipality, city or government.

**Floating**: Dummy variable that enters 1 if the bond has a floating coupon rate, 0 if the bond has a fixed rate.

## 3.5 Descriptive Statistics

Studying **Table 1** we see that the daily ASW average for the period is lower for green bonds. However, the standard deviation of daily ASW for brown bonds is notably higher. The average issued amount is lower for green bonds. The average maturity for all bonds in our data sample is around 5 years and is somewhat higher for brown bonds. The average monthly bid-ask spread is higher for green bonds.

Table 1
**Descriptive Statistics for Green and Brown Bonds**
Table showing summary statistics including number of observations, mean, 25th, 50th and 75th percentile, minimum and maximum value as well as standard deviation for the main quantitative variables. Data is split by green and brown bonds

| | count | mean | p25 | p50 | p75 | min | max | sd |
|---|---|---|---|---|---|---|---|---|
| **Brown** | | | | | | | | |
| ASW (bp) | 138463 | 84.93 | 37.85 | 61.25 | 90.92 | -65.54 | 9373.19 | 232.10 |
| Bid-Ask Spread (bp) | 135040 | 55.70 | 27.94 | 34.25 | 56.57 | .40 | 2500.00 | 68.92 |
| Amount (SEKm) | 154000 | 5979.01 | 200.00 | 400.00 | 800.00 | 15.00 | 97310.00 | 15866.50 |
| Maturity (years) | 155566 | 5.75 | 5.00 | 5.00 | 6.01 | .53 | 30.02 | 2.82 |
| Days to Maturity | 155566 | 1560.06 | 982.00 | 1413.00 | 1795.00 | 0.00 | 10741.00 | 1044.45 |
| **Green** | | | | | | | | |
| ASW (bp) | 13998 | 46.72 | 20.62 | 44.77 | 68.01 | -12.80 | 203.32 | 35.77 |
| Bid-Ask Spread (bp) | 13771 | 70.24 | 29.82 | 46.74 | 95.48 | -44.63 | 858.28 | 65.65 |
| Amount (SEKm) | 14886 | 732.74 | 310.00 | 500.00 | 1000.00 | 150.00 | 5000.00 | 759.89 |
| Maturity (years) | 14886 | 5.11 | 5.00 | 5.02 | 6.01 | 2.33 | 7.01 | 1.13 |
| Days to Maturity | 14886 | 1360.52 | 960.00 | 1439.00 | 1744.00 | 53.00 | 2557.00 | 505.30 |

Studying **Table 2**, we see that the credit rating distribution does not differ notably between the two groups. An exception is a higher percentage of green bonds having credit rating BBB. There are no bonds with a rating of B or below in our sample. We control for the rating effect with the dummy variables for credit rating. As of issue year, the main differences are that it is a lower percentage of green bonds that has been issued 2013 and a higher percentage issued 2016. This is a natural consequence of the rapid development of the green bond market, see section 1. In effect, this leads to more observations for 2016-2017 than for earlier years and we control for this by using time fixed effects and also by studying the regression results over time. As of issuer type, green bonds have a higher percentage official issuers, probably as a consequence of official actors being strong promoters of the green bond market, see section 1. The dummy variable for corporate issuer controls for this effect.

Table 2
**Sample Distribution of Credit Rating, Issue Year and Issuer Type**
Table showing the sample distribution in percentage split by green and brown bonds for the following variables; credit rating, issue year and issuer type

| | Credit Rating | | | | | | Issue year | | | | | Issuer type | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | AAA | AA | A | BBB | BB | N/A | 2013 | 2014 | 2015 | 2016 | 2017 | Corporate | Official |
| **Green** | 25% | 19% | 38% | 16% | 3% | 0% | 3% | 22% | 13% | 31% | 31% | 63% | 38% |
| **Brown** | 22% | 19% | 33% | 4% | 3% | 18% | 9% | 19% | 19% | 21% | 32% | 82% | 18% |

## 3.6 Econometric Study Design

Our data collection results in a panel data set of 111,890 observations that can be used for regressions. To find the initial direction of our results, we start with a basic OLS regression of the ASW on the explanatory variables. Further, as mentioned in the previous section, we use time fixed effects on a yearly basis to control for the fact that the market has developed rapidly during the last years but also to account for slightly different market conditions over the years. Since most of our explanatory variables are of dummy type, we use the dummy type time fixed effects, in line with guidance from Wooldridge (2003). However, since we have time series cross-sectional data, there is reason to expect contemporaneous correlation across panels[12] and panel-specific heteroskedasticity. To further refine the regression, we therefore use a method called Prais-Winsten (xtpcse), which uses panel-corrected standard errors and in which we are able to adjust for serial correlation across panels and bond-specific heteroskedasticity (Bailey and Katz, 2011). To account for the possibility that our variables do not fully explain yield and to better quantify the "true" yield difference between green and brown bonds, we also use the Oaxaca-Blinder decomposition that Karpf and Mandel (2017 and 2018) base their findings on. In contrast to Karpf and Mandel (*ibid*), we perform a threefold decomposition. The advantage of the threefold decomposition is that it does not rely on an exogenously provided estimate for the nondiscriminatory coefficients vector (Jann, 2008). To test the reliability of our model and our

[12] The panels in our study corresponds to individual bonds

regression methods, we test altered versions of the main model and perform a series of robustness tests, further described in section 4.3.

Another method used to compare bond yields is matching (Goldreich et al. (2005), Zerbib (2017)), in which yield differences between bonds with the same characteristics except for the trait studied are compared. This method would probably have better isolated potential differences between green and brown bonds. However, given the limited number of green bonds, we do not find enough green and brown bond pairs from the same issuer with the same maturity date. Zerbib (2017) uses a modified matching method in which the requirement for same maturity date is relaxed to a time interval of two years. Using a maturity difference of two years would still limit our sample significantly and since Karpf and Mandel (2017 and 2018) and Chen et al. (2007) use non-matching methods, we choose to perform the regression methods described above.

# IV. Analysis & Findings

## 4.1 Examining a Yield Difference

*4.1.1 Is There a Yield Difference Between Green and Brown Bonds?*

Comparing the ASW over days to maturity for green and brown bonds in **Figure 2**, we see an indication towards green bonds on average yielding a lower ASW than brown bonds. Despite widely scattered values, the linear trend shows decreasing ASW for both bond types closer to maturity, which is in line with the time to maturity effect in bond pricing theory (Berk and DeMarzo, 2014).

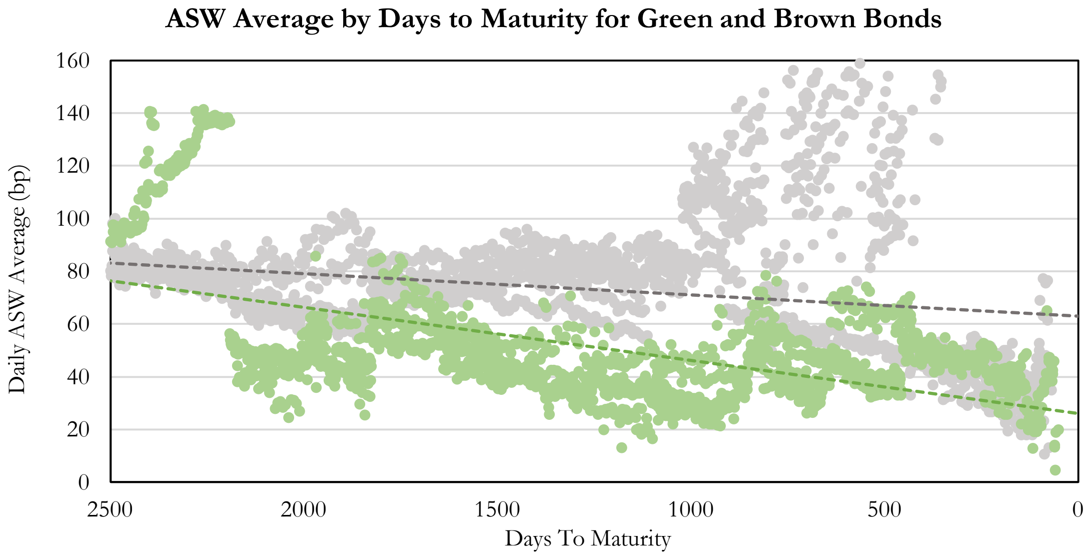


**Figure 2**: Scatter plot of daily ASW average over days to maturity for green (green colored) and brown bonds (gray colored). The hashed lines represent linearly fitted trend lines, the green colored for green bonds and the gray colored for brown bonds. Presented by decreasing days to maturity

To see whether there is a statistically significant yield difference between green and brown bonds, we examine the results with an OLS regression, an OLS with time fixed effects (using dummy variables for year) and a Prais-Winsten regression. We hereafter refer to the regressions in this section as the **Original Regressions.** The OLS and the Prais-Winsten regressions are described as the following:

$$ASW_{it} = \alpha_0 + \alpha_1 Green_i + \alpha_2 BidAsk_{it} + \alpha_3 Rating\_AA_i + \alpha_4 Rating\_A_i + \alpha_5 Rating\_BB\_BBB_i + \alpha_6 DTM_{it} + \alpha_7 Corporate_i + \alpha_8 Amount_i + \alpha_9 Floating_i + \varepsilon_{it}$$

The OLS with year fixed effects (areg) is a standard regression where we create a dummy variable for each year, except for the base year 2013. The regression "absorbs" the year dummies, why the year dummy coefficients are not presented **Table 3**. The OLS with year fixed effects (areg) is described as the following.

$$ASW_{it} = \alpha_0 + \alpha_1 Green_i + \alpha_2 BidAsk_{it} + \alpha_3 Rating\_AA_i + \alpha_4 Rating\_A_i + \alpha_5 Rating\_BB\_BBB_i + \alpha_6 DTM_{it} + \alpha_7 Corporate_i + \alpha_8 Amount_i + \alpha_9 Floating_i + \alpha_{10} yr\_2014_i + \alpha_{11} yr\_2015_i + \alpha_{12} yr\_2016_i + \alpha_{13} yr\_2017_i + \varepsilon_{it}$$

The results for the regressions presented are reported in **Table 3**. The dummy variable for the green classification is significant at the 0.1-percent level in all three regression methods which provides a first insight to whether bonds with the green classification are priced differently. The green coefficient is similar in all three regressions (between -3.82 to -3.15), which supports the robustness of the coefficient. The interpretation of the coefficient being around -3 is that a bond with a green classification yields a 3 basis points lower ASW than its brown counterparty.

The proxy for liquidity, monthly bid-ask spread, is significant at the 0.1-percent level in both OLS regressions but is not significant in the serial correlation adjusted Prais-Winsten regression. We will examine the liquidity effect further in section 4.2.

The rest of the explanatory variables are significant at the 0.1-percent level in all three regressions. As of rating, the positive coefficient decreasing with improving credit rating implies that a higher credit risk yields higher ASW than better rated counterparties, which is in line with the theory on credit risk premium presented in subsection 2.2.1. The positive coefficient for days to maturity implicates a higher yield for bonds further from maturity, which is in line with the increased interest rate risk. The positive coefficient for the corporate dummy variable suggests that a bond of a corporate issuer yields higher ASW than a non-corporate issuer. Amount has a positive coefficient which indicates that a larger principal issue size yields lower ASW, which stands in contrast to the findings of Karp and Mandel (2018) but is in line with Longstaff et al. (2005) and Fischer (1959). The floating coupon dummy shows a negative coefficient which is interpreted as bonds with floating coupon rate yielding lower ASW than ones with fixed coupon rate. This is in line with the previous outlined suggestion that investors value bonds with floating coupon higher than bonds with fixed coupon rate.

We find the explanatory power of our model rather strong based on observed $R^2$ values of 42% and 48%. Using time fixed effects on year generates a higher $R^2$. This does not necessarily imply that the model is improved by time fixed effects, as it could simply be an effect of the added year dummy variables (Wooldridge, 2003). No $R^2$ value is obtained for the Prais-

Winsten regression. To test the power of our explanatory variables we also perform a regression with stepwise addition of the variables, see **Table 11** in Appendix A.

Table 3

**Original Regressions of ASW for Green and Brown Bonds**

Table showing results of three regressions of daily ASW. The first regression is an OLS regression with robust standard errors[13] called reg. The second is an OLS regression with robust standard errors with year fixed effects (dummy type) called areg, absorbing the year dummies. The third is a Prais-Winsten regression estimating panel-corrected standard errors, adjusted for panel-specific heteroskedasticity and serial correlation[14] called xtpcse[15]. The first equation is for OLS and Prais-Winsten, the second one for OLS with year fixed effects

$$ASW_{it} = \alpha_0 + \alpha_1 Green_i + \alpha_2 BidAsk_{it} + \alpha_3 Rating\_AA_i + \alpha_4 Rating\_A_i + \alpha_5 Rating\_BB\_BBB_i + \alpha_6 DTM_{it} + \alpha_7 Corporate_i + \alpha_8 Amount_i + \alpha_9 Floating_i + \varepsilon_{it}$$

$$ASW_{it} = \alpha_0 + \alpha_1 Green_i + \alpha_2 BidAsk_{it} + \alpha_3 Rating\_AA_i + \alpha_4 Rating\_A_i + \alpha_5 Rating\_BB\_BBB_i + \alpha_6 DTM_{it} + \alpha_7 Corporate_i + \alpha_8 Amount_i + \alpha_9 Floating_i + \alpha_{10} yr\_2014_i + \alpha_{11} yr\_2015_i + \alpha_{12} yr\_2016_i + \alpha_{13}\, yr\_2017_i + \varepsilon_{it}$$

The explanatory variables are; Green: dummy variable taking the value 1 if the bond is classified as green, BidAsk: monthly average of bid-ask spread (bp), Rating: dummy variables for the rating steps AA, A and BB/BBB on a S&P equivalent scale, with AAA being the comparable group, DTM: days to maturity, Corporate: dummy variable taking the value 1 if the issuer is corporate, Floating: dummy variable taking the value 1 if the coupon rate is floating, Amount: principal amount issued (SEKm)

| | (1)<br>OLS (reg) | (2)<br>OLS with year fixed effects (areg) | (3)<br>Prais-Winsten (xtpcse) |
|---|---|---|---|
| Green | -3.678*** | -3.150*** | -3.815*** |
| | (-11.46) | (-10.29) | (-8.16) |
| Bid Ask Spread (bp) | 0.00645*** | 0.0102*** | 0.00209 |
| | (5.40) | (9.93) | (1.39) |
| Credit Rating AA | 13.48*** | 13.05*** | 13.57*** |
| | (58.11) | (60.96) | (30.91) |
| Credit Rating A | 13.55*** | 13.11*** | 13.73*** |
| | (64.59) | (70.41) | (37.79) |
| Credit Rating BBB or BB | 56.05*** | 55.20*** | 56.73*** |
| | (71.34) | (72.57) | (63.13) |
| Days to Maturity | 0.0125*** | 0.0121*** | 0.0124*** |
| | (171.20) | (182.75) | (82.09) |
| Corporate | 28.68*** | 28.63*** | 28.39*** |
| | (127.54) | (134.98) | (64.83) |
| Issue Amount (SEKm) | -0.000716*** | -0.000737*** | -0.000715*** |
| | (-163.64) | (-178.40) | (-124.07) |
| Floating | -60.85*** | -62.03*** | -61.88*** |
| | (-61.95) | (-62.06) | (-59.61) |
| Observations | 111890 | 111890 | 111890 |
| Adjusted $R^2$ | 0.423 | 0.480 | |

*t* statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[13] Using robust standard errors on basis of positive heteroskedasticity test, see section 4.3

[14] Adjusting for first order serial correlation on basis of test, see section 4.3

[15] No $R^2$-value is obtained for Prais-Winsten

*4.1.2 Is the Yield Difference Consistent Over Time?*

We find a significant negative yield premium for green bonds, but is it consistent over time? The reason we explore this is to see if there is a historical trend but also to test the robustness of the previous findings. Studying the average ASW over time in **Figure 3**, we see that green bonds on average has yielded a lower ASW than brown bonds for the period. The difference seems to be less pronounced over time, especially after September 2016.

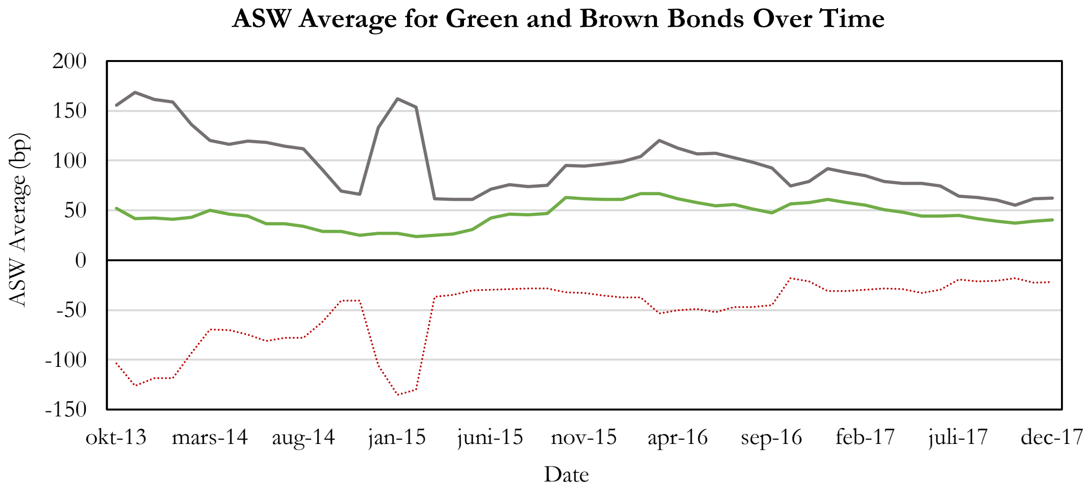


**Figure 3**: Time series of ASW average for green (green colored) and brown (gray colored) bonds from October 2013 to December 2017. The dotted red line represents the difference in ASW average between green and brown bonds for the period

To see whether this observation holds true, we perform regressions for each individual year[16] with the serial correlation adjusted panel-method Prais-Winsten. The results, presented in **Table 4**, show that the coefficient for the green classification is significant at the 0.1-percent level for each year throughout the period. The coefficient is negative from 2013 to 2016 and positive for 2017. We interpret the decreasingly negative coefficient, in line with **Figure 3**, as an implication of a decreasing ASW difference between green and brown bonds throughout the period. The positive coefficient for 2017 stands in contrast to the overall negative green yield premium conclusion drawn from the **Original Regressions**, but it is not necessarily contradictory. To more precisely quantify the yearly difference, we perform an Oaxaca-Blinder decomposition in the next subsection.

[16] Since we only have observations for three months in 2013, we combine 2013 and 2014 in the first period

As of liquidity, the coefficient for bid-ask spread is only significant in 2015 and 2017, which will be addressed in section 4.2. As for the other explanatory variables, results are more or less in line with results from the **Original Regressions** with the exception of non-significant coefficients for credit rating AA and issuer type for the period 2013-2014. This might be explained by a limited number of observations with those characteristics during that period.

Table 4

**Prais-Winsten Regressions of ASW for Green and Brown Bonds Over Time**

Table showing results of Prais-Winsten regressions of daily ASW over time. All are Prais-Winsten regressions estimating panel-corrected standard errors, adjusted for panel-specific heteroskedasticity and serial correlation[17] called xtpcse[18]. The first regression represents the whole period and regression 2-5 represents each individual year[19]

$$ASW_{it} = \alpha_0 + \alpha_1 Green_i + \alpha_2 BidAsk_{it} + \alpha_3 Rating\_AA_i + \alpha_4 Rating\_A_i + \alpha_5 Rating\_BB\_BBB_i + \alpha_6 DTM_{it} + \alpha_7 Corporate_i + \alpha_8 Amount_i + \alpha_9 Floating_i + \varepsilon_{it}$$

The variables are: Green: dummy variable taking the value 1 if the bond is classified as green, BidAsk: monthly average of bid-ask spread (bp), Rating: dummy variables for the rating steps AA, A and BB/BBB on a S&P equivalent scale, with AAA being the comparable group, DTM: days to maturity, Corporate: dummy variable taking the value 1 if the issuer is corporate, Floating: dummy variable taking the value 1 if the coupon rate is floating, Amount: principal amount issued (SEKm)

| | Prais-Winsten (xtpcse) | | | | |
|---|---|---|---|---|---|
| | (1)<br>Whole period | (2)<br>2013-2014 | (3)<br>2015 | (4)<br>2016 | (5)<br>2017 |
| Green | -3.815*** | -25.57*** | -14.59*** | -5.253*** | 4.016*** |
| | (-8.16) | (-15.26) | (-11.39) | (-5.75) | (9.36) |
| Bid Ask Spread (bp) | 0.00209 | -0.00525 | 0.0116** | -0.0000242 | 0.00441* |
| | (1.39) | (-1.12) | (2.64) | (-0.01) | (2.47) |
| Credit Rating AA | 13.57*** | -1.673 | 9.098*** | 13.76*** | 15.26*** |
| | (30.91) | (-1.76) | (9.67) | (16.66) | (34.48) |
| Credit Rating A | 13.73*** | 17.81*** | 12.07*** | 14.24*** | 11.50*** |
| | (37.79) | (19.72) | (13.32) | (22.31) | (31.64) |
| Credit Rating BBB or BB | 56.73*** | 88.67*** | 61.79*** | 61.75*** | 37.65*** |
| | (63.13) | (37.42) | (30.50) | (30.18) | (49.30) |
| Days to Maturity | 0.0124*** | 0.00953*** | 0.00800*** | 0.0139*** | 0.0143*** |
| | (82.09) | (33.78) | (18.75) | (50.85) | (92.88) |
| Corporate | 28.39*** | -0.579 | 14.11*** | 35.85*** | 31.94*** |
| | (64.83) | (-0.54) | (15.28) | (41.06) | (74.15) |
| Issue Amount (SEKm) | -0.000715*** | -0.000848*** | -0.000713*** | -0.000816*** | -0.000742*** |
| | (-124.07) | (-45.93) | (-46.40) | (-85.31) | (-108.97) |
| Floating | -61.88*** | -68.62*** | -63.48*** | -73.91*** | -47.69*** |
| | (-59.61) | (-23.82) | (-31.45) | (-32.46) | (-34.26) |
| Observations | 111890 | 10743 | 20495 | 31539 | 49113 |

*t* statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[17] Adjusting for heteroskedasticity and first order serial correlation on basis of tests, see section 4.3
[18] No $R^2$-value is obtained for Prais-Winsten
[19] We combine 2013 and 2014 in the first period, since we only have observations for three months in 2013

*4.1.3 Is the Yield Difference Consistent When Decomposing the Effect of Data Characteristics?*

The earlier findings of an ASW difference are based on models that aim to explain if there is a significant dummy variable for the green classification when controlling for other variables affecting yield. To more accurately quantify the green effect, we choose to decompose the ASW difference into data related effects and the "true" green effect. We perform an **Oaxaca-Blinder Decomposition** in similarity with Karpf and Mandel (2017 and 2018), an approach that traditionally has been used to explain the wage gaps between groups (Blinder (1973), Oaxaca (1973)). In contrast to Karpf and Mandel (*ibid*), we perform a threefold decomposition, see section 3.6. The logic of the decomposition is to calculate the total mean difference in ASW (R) between the two groups brown (A) and green (B) bonds.

$$R = E(Y_A) - E(Y_B)$$

E(Y) denotes the expected value of the dependent variable that comes from group differences in the explanatory variables. X is a vector containing the predictors and a constant, $\beta$ contains the slope parameters and the intercept. Following the mathematical approach outlined in Appendix B, the procedure results in a threefold decomposition where the total mean difference is split up into three parts:

$$R = E + C + I$$

The first component represents the endowments effect (E). It is the difference that can be explained by differences in data characteristics in the explanatory variables for the two groups:

$$E = (E(Y_A) - E(Y_B))'\beta_B$$

The second part represents the coefficients effect (C). It is the contribution of differences of the coefficients, including differences of the intercept. It can be interpreted as the unexplained part of the difference:

$$C = E(X_B)'(\beta_A - \beta_B)$$

The third term is the interaction effect, which accounts for simultaneous differences in both E and C in the two groups:

$$I = (E(X_A) - E(X_B))'(\beta_A - \beta_B)$$

The full method description of the decomposition is presented in Appendix B. The interpretation of the decomposition is that the total difference is the average difference between ASW for brown and ASW for green bonds. A positive difference denotes that green bonds on average trade at lower yields than brown bonds. The endowment is the difference in mean ASW that can be explained by data characteristics captured by the explanatory variables, e.g. if green bonds on average have lower rating and lower rating is estimated to yield a lower ASW, then the decomposition expects the total difference to be greater. The interaction is the component that measures the simultaneous effect of differences in endowments and coefficients. The coefficient is the part of the difference that cannot be explained by mean differences in the explanatory variables between the two groups. It is also referred to as the unexplained part and usually attributed to be the discrimination effect (Jann, 2008). The coefficient can in this setting be interpreted as the "true" green effect. A shortcoming of the interpretation is that there is a risk that the unexplained part also captures other effects that are not explained by the model and not related to the green effect.

The results analyzed are presented in **Table 5** below, see **Table 8** in Appendix A for the complete regression output for the whole period. The total mean difference for the whole period is significant at the 1-percent level with a value of 13.5 bp. The difference is significant and decreasing over time. We need to study the coefficients (the unexplained difference) to separate the green effect from what is expected due to the data characteristics. The unexplained difference for the whole period is significant at the 1-percent level with a value of 12.9 bp. It is also significant at the 1-percent level over time, being largest in 2013-2014 at a value of 29.4 bp and steadily decreasing over time to a value of 1.2 bp in 2017. The interpretation of this is that even if green and brown bonds would have had exactly the same data characteristics (in terms of rating etc.), green bonds would still have a 12.9 basis points lower yield than brown bonds.

The Oaxaca-Blinder decomposition contributes with three major implications for the interpretation of the results. In contrast to Prais-Winsten, Oaxaca-Blinder claims the existence of a small, but yet negative green yield premium in 2017. Given the characteristics of the decomposition, we recognize the Oaxaca-Blinder to be the most reliable method to *quantify* the difference. Further, it supports the decreasing pattern of the green yield spread from 2013-2014 to 2017. Lastly, the similarity of the results, when comparing OLS, Prais-Winsten and Oaxaca-Blinder, increase our confidence in the existence of a negative green yield premium in the Swedish market. The negative green yield premium for the whole period, that cannot be explained by data characteristics, is best quantified to 12.9 basis points.

Table 5

**Oaxaca-Blinder Decomposition of ASW Difference Between Green and Brown Bonds Over Time**

Table showing results from threefold Oaxaca-Blinder decomposition over time. All are Oaxaca-Blinder decompositions estimating the endowment, coefficient and interactive part of the ASW mean difference between the two groups green and brown bonds[20]. The first regression represents the whole period and regression 2-5 represents each individual year[21].

$R = E(Y_A) - E(Y_B)$ and $R = E + C + I$ [22]

The explanatory variables are; BidAsk: monthly average of bid-ask spread (bp), Rating: dummy variables for the rating steps AA, A and BB/BBB on a S&P equivalent scale, with AAA being the comparable group, DTM: days to maturity, Corporate: dummy variable taking the value 1 if the issuer is corporate, Floating: dummy variable taking the value 1 if the coupon rate is floating, Amount: principal amount issued (SEKm)

| | Oaxaca-Blinder Decomposition | | | | |
|---|---|---|---|---|---|
| | (1) Overall | (2) 2013-2014 | (3) 2015 | (4) 2016 | (5) 2017 |
| Brown | 61.25389*** (.1524272) | 64.84668*** (.5575817) | 68.47709*** (.371639) | 77.59408*** (.3254981) | 46.72687*** (.1672002) |
| Green | 47.71234*** (.3190595) | 34.74663*** (.7564058) | 43.76996*** (.6561893) | 58.33146*** (.6849296) | 45.76455*** (.464122) |
| difference | 13.54155*** (.3536001) | 30.10005*** (.9397058) | 24.70714*** (.754122) | 19.26261*** (.7583387) | .9623226* (.4933206) |
| endowments | 22.63774*** (1.526331) | 376.0948*** (11.81196) | 531.9351*** (13.71959) | 26.2383*** (3.31414) | 6.385989*** (1.041185) |
| coefficients | 12.87561*** (.406541) | 29.39513*** (2.923801) | 25.82751*** (1.066741) | 15.32849*** (.8951004) | 1.203522*** (.379557) |
| interaction | -21.97179*** (1.534329) | -375.3899*** (12.29598) | -533.0555*** (13.83769) | -22.30417*** (3.331858) | -6.627188*** (.9818337) |
| Observations | 111,890 | 10,743 | 20,495 | 31,539 | 49,113 |

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

[20] A complete table of the regression for the whole period is shown in **Table 8** in Appendix A
[21] We combine 2013 and 2014 in the first period, since we only have observations for three months in 2013
[22] See Appendix B for the complete decomposition

## 4.2 Examining a Liquidity Effect on Yield

*4.2.1 Is There a Difference in the Liquidity Effect on Yield for Green and Brown Bonds?*

Drawing upon our secondary research question, we want to study if there is a difference in how liquidity affects yield between green and brown bonds. If such a difference exists, it could help to explain the pricing discrepancy found in section 4.1. The overall flat trend in **Figure 4** give a first indication that there might not be a clear relationship between liquidity and ASW. Comparing green bonds with brown, the trend seems ambiguous. The trend for brown bonds is slightly negative and the trend for green bonds seems to be flat. However, we see that brown bonds have lower and less scattered bid-ask spread values than green bonds.

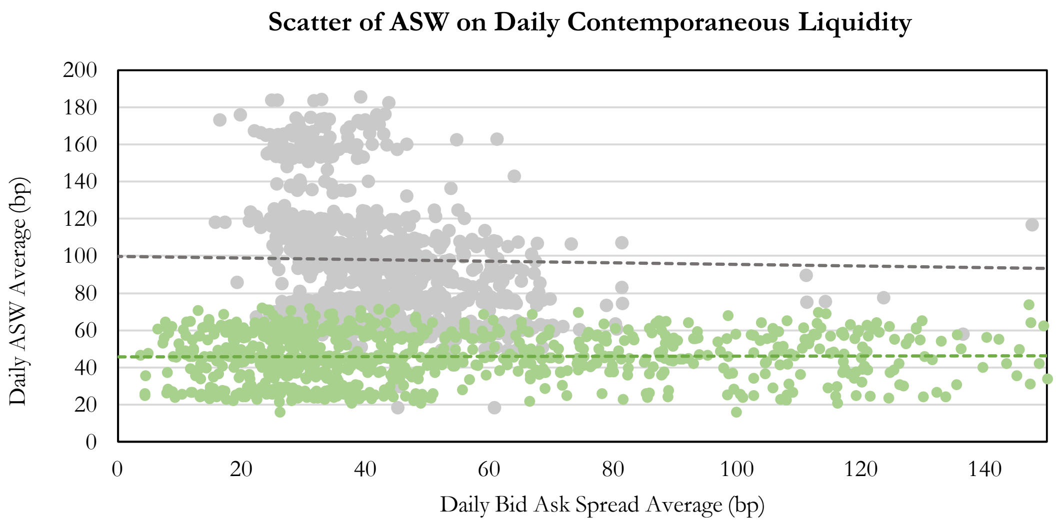


**Figure 4**: Scatter plot of daily ASW average on daily bid-ask spread average for green and brown bonds. The hashed lines represent linearly fitted trend lines, the green colored for green bonds and the gray colored for brown bonds. Some outlying observations has been left out from the plot area to better illustrate the relationship

Recalling the results from the **Original Regressions** in **Table 3**, we found the bid-ask coefficient to be positive and significant for both OLS regressions, but not significant for the autocorrelation adjusted Prais-Winsten. We interpret this as the following: there might be a liquidity effect on the yield (higher yield for less liquid bonds), but there is reason to question this relationship as the results do not hold after adjustment for potential autocorrelation disturbances[23].

[23] Autocorrelation found in test outlined in section 4.3 and **Table 9** in Appendix A

However, the result does not tell us whether there is a difference in how green and brown yields are affected by liquidity. To study the potential liquidity effect of the green classification, we construct the two following interactive dummy variables.

$$Green\_BidAsk = Green * BidAsk$$
$$Brown\_BidAsk = Brown^{24} * BidAsk$$

The regressions with the new variables are hereafter referred to as the **Liquidity Effect Regressions**. The OLS with year fixed effects is described as the following.

$$\begin{aligned} ASW_{it} = \beta_0 &+ \beta_1 Green_i + \beta_2 Green\_BidAsk_{it} + \beta_3 Brown\_BidAsk_{it} + \beta_4 Rating\_AA_i \\ &+ \beta_5 Rating\_A_i + \beta_6 Rating\_BB\_BBB_i + \beta_7 DTM_{it} + \beta_8 Corporate_i + \beta_9 Amount_i \\ &+ \beta_{10} Floating_i + \beta_{11} yr\_2014_i + \beta_{12} yr\_2015_i + \beta_{13} yr\_2016_i + \beta_{14} yr\_2017_i \\ &+ \varepsilon_{it} \end{aligned}$$

The Prais-Winsten regression is described as the following.

$$\begin{aligned} ASW_{it} = \beta_0 &+ \beta_1 Green_i + \beta_2 Green\_BidAsk_{it} + \beta_3 Brown\_BidAsk_{it} + \beta_4 Rating\_AA_i \\ &+ \beta_5 Rating\_A_i + \beta_6 Rating\_BB\_BBB_i + \beta_7 DTM_{it} + \beta_8 Corporate_i + \beta_9 Amount_i \\ &+ \beta_{10} Floating_i + \varepsilon_{it} \end{aligned}$$

The results for the **Liquidity Effect Regressions** are presented in **Table 6**. The variables left unaltered from the **Original Regressions** (Green, Rating, Corporate, DTM, Amount and Floating) does not change notably. To avoid repetitiveness, we choose to only display the results for the new variables. Both variables are significant at the 0.1-percent level in the OLS regression with year fixed effects (areg) with slightly positive coefficients. This result implies what is in line with previous studies (Chen et al., 2007), that an increase in bid-ask spread and thus a decrease in liquidity yields higher ASW. The coefficient for interaction between liquidity and green (0.0241) is about 2.8 times larger than the coefficient for brown (0.00856), indicating that liquidity might affect green bond yields more than brown bond yields. However, none of the coefficients are significant in the serial correlation adjusted Prais-Winsten regression which like in **Original Regressions** makes us skeptic towards the liquidity results of the OLS regression.

[24] Brown is the inverted version of the Green variable, which enters the value of 1 if the bond is not classified as green

Table 6

**Liquidity Effect Regressions of ASW for Green and Brown Bonds**

Results for regressions of daily ASW. The first regression is an OLS regression with robust standard errors[25] and time fixed effects on year (dummy type). The second regression is a Prais-Winsten regression estimating panel-corrected standard errors, adjusted for heteroskedasticity and serial correlation[26] called xtpcse[27]. Results only shown for Green_BidAsk and Brown_BidAsk The first equation is for OLS with year fixed effects, the second for Prais-Winsten.

$$ASW_{it}=\beta_0+\beta_1 Green_i+\beta_2 Green\_BidAsk_{it}+\beta_3 Brown\_BidAsk_{it}+\beta_4 Rating\_AA_i+\beta_5 Rating\_A_i+\beta_6 Rating\_BB\_BBB_i+\beta_7 DTM_{it}+\beta_8 Corporate_i+\beta_9 Amount_i+\beta_{10} Floating_i+\beta_{11} yr\_2014_i+\beta_{12}\ yr\_2015_i+\beta_{13} yr\_2016_i+\beta_{14} yr\_2017_i+\varepsilon_{it}$$

$$ASW_{it}=\beta_0+\beta_1 Green_i+\beta_2 Green\_BidAsk_{it}+\beta_3 Brown\_BidAsk_{it}+\beta_4 Rating\_AA_i+\beta_5 Rating\_A_i+\beta_6 Rating\_BB\_BBB_i+\beta_7 DTM_{it}+\beta_8 Corporate_i+\beta_9 Amount_i+\beta_{10} Floating_i+\ \varepsilon_{it}$$

The variables are; Green: dummy variable taking the value 1 if the bond is classified as green, Green_BidAsk: monthly average of bid-ask spread (bp) for green bonds, Brown_BidAsk: monthly average of bid-ask spread (bp) for brown bonds, Rating: dummy variables for rating steps AA, A and BB/BBB on a S&P equivalent scale, with AAA being the comparable group, DTM: days to maturity, Corporate: dummy variable taking the value 1 if the issuer is corporate, Floating: dummy variable taking the value 1 if the coupon rate is floating, Amount: principal amount issued (SEKm)

| | (1)<br>OLS year fixed effects (areg) | (2)<br>Prais-Winsten (xtpcse) |
|---|---|---|
| Interaction Green & Bid Ask Spread (bp) | 0.0241$^{***}$ | 0.00493 |
| | (6.33) | (1.66) |
| Interaction Brown & Bid Ask Spread (bp) | 0.00856$^{***}$ | 0.00166 |
| | (7.61) | (0.99) |
| Observations | 111890 | 111890 |
| Adjusted $R^2$ | 0.480 | |

*t* statistics in parentheses
$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

### *4.2.2 Does the Liquidity Effect on Yield Change Over Time?*

Studying **Figure 5** of average liquidity over time, we see a fragmented trend of the difference between green and brown bonds. This is probably inferred by the scattered values, especially for green bonds. We interpret the overall trend to be that green bonds on average have had somewhat higher bid-ask spread and thus lower liquidity than brown bonds throughout the period.

[25] Using robust standard errors on basis of positive heteroskedasticity test, see section 4.3
[26] Adjusting for serial correlation on basis of test, see section 4.3
[27] No $R^2$ value obtained for Prais-Winsten

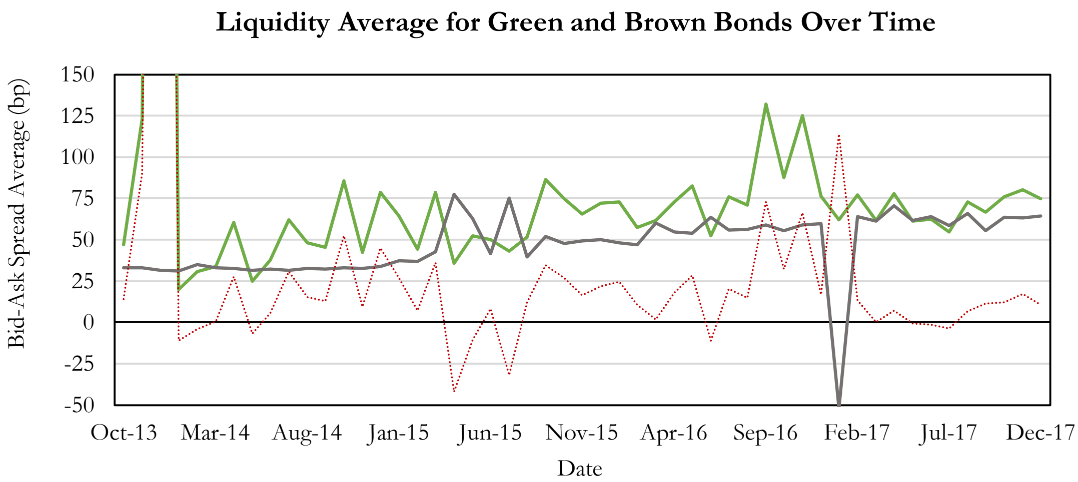


**Figure 5**: Time series of monthly bid-ask spread average for green (green colored) and brown (gray colored) bonds from October 2013 to December 2017. The dotted red line represents the difference in bid-ask spread average between green and brown bonds for the period. Some outlying observations have been left out of the plot area to better illustrate the relationship

Recalling the Prais-Winsten results from the **Original Regressions** over time (see **Table 4**), the coefficients for the overall liquidity effect are only significant 2015 (1-percent level) and 2017 (5-percent level). In those years the coefficients are positive. We interpret this as a confirmation of earlier conclusions: there might be a positive relationship between bid-ask spread and yield, but we should be cautious to draw conclusions about this.

## 4.3 Further Robustness Tests

### *4.3.1 Multicollinearity, Heteroskedasticity and Serial Correlation*

To test the robustness of our regressions, we have performed tests for multicollinearity, heteroskedasticity and serial correlation for the **Original Regressions**. We choose to only display results for these regressions since the **Oaxaca-Blinder Decomposition** and the **Liquidity Effect Regressions** include the same or versions of the same variables. As of multicollinearity, we perform a test of the variance inflated factors (VIFs) of the independent variables and find that we do not have multicollinearity problems.

To test the presence of heteroskedasticity in the residuals, we perform a Breusch-Pagan/Cook-Weisberg test and the results imply presence of heteroskedasticity. To obtain more reliable results, the regressions are therefore adjusted for this. For the basic OLS regressions and for the Oaxaca-Blinder decomposition we use robust standard errors. For the panel-regression

Prais-Winsten we adjust for panel-specific heteroskedasticity, which is a more sophisticated way of dealing with heteroskedasticity (Wooldridge, 2003).

We have reason to expect serial correlation for the ASW parameter, similar to the time varying and mean reverting pattern of the yield spread found by Longstaff et al. (2005). Therefore, we perform a Wooldridge test for serial correlation in panel data and the results, presented in **Table 9** in Appendix A, show that there is reason to suspect first order autocorrelation. To adjust for this, we use Prais-Winsten adjusted for first order autocorrelation. We do not adjust for panel-specific autocorrelation, since one major drawback of that is that the estimation would be based on less observations (one estimation per panel), which makes the autocorrelation adjustment less reliable (Beck and Katz, 1995).

*4.3.2 Robustness of the Bid-Ask Spread Variable*

To justify our choice of the monthly bid-ask spread, we perform the original OLS regression (with robust standard errors) alternating with daily, weekly, quarterly and yearly bid-ask spread. The results, shown in **Table 10** in Appendix A, show that the monthly bid-ask spread variable constitutes the best compromise between number of observations and frequency of the liquidity measure. For example, even though daily bid-ask spread generates the highest $R^2$ value, the number of observations would decrease from around 120k to 24k, which affects the reliability of the result. Using quarterly bid-ask spread does not notably increase the number of observations and since such aggregation of the variable would make it less detailed, we conclude that monthly bid-ask spread is the most accurate measure for our model given our data set.

# V. Discussion & Critical Reflections

## 5.1 Potential Explanations

Given the limited research in the field, we can only speculate about potential explanations for our findings. We find a significant negative green bond yield premium in the Swedish secondary market. The results are coherent with what Zerbib (2017) found globally and with what Karpf and Mandel (2018) found in the US from 2015 and forward. The view that green bonds currently have lower yield than brown bonds is also supported by stakeholders in the Swedish bond market. We find the negative green premium to be decreasing over time, which could imply a shift towards smaller price discrepancies as the market matures. A potential explanation for the green expensiveness could be the considerable demand from institutional investors for sustainable investments in combination with the relatively small supply, which pushes up prices and drives down yield for green bonds. The price discrepancy observed in the secondary market is thus probably closely related to the greenium that has been observed for green issuances in the primary market. The buy-and-hold behavior of green investors, experienced by our interviewees, could further negatively affect the supply of green bonds in the secondary market. The green buy-and-hold behavior is however subject to further research.

Another potential explanation for the negative green premium could be related to the information advantage that comes with buying a bond with a green classification, as it enables the investor to gain better insight to the use of proceeds. This would be true if the investor is committed to invest in sustainable projects and at the same time value the decreased searching cost that comes with buying an already certified instrument.

We find ambiguous results for the relationship between liquidity and yield, with robust coefficients for 2015 and 2017 solely. There seems to be a green liquidity effect when the results are significant, but we interpret this effect with caution due to model's unsatisfying identification of an overall robust relationship. Our results are somewhat contrary to the findings of Chen et al. (2007), who find a clear relationship between liquidity and yield. Potential sources of improvement in this regard is to use complementary liquidity proxies such as LOT, turnover volume and transaction frequency to better capture the mechanisms of liquidity.

Additionally, the possible supply-demand gap and buy-and-hold behavior of green investors probably limits green bond liquidity and thus affect our liquidity results. The young age of the green bond market could in turn help to explain the proposed supply-demand gap. It will therefore be interesting to see research of the subject in a couple of years, when the market is presumably more saturated. Current research should extend the field with supply-demand analysis and examination of the primary market to further unravel a potential green liquidity effect.

Lastly, one has to bear in mind that we are studying the relatively local SEK bond market, in contrast to other practitioners such as Karpf and Mandel (2017 and 2018) and Chen et al. (2007), who study more global and liquid markets such as the USD market. Research in the field in Sweden is scarce and should be subject to future research.

## 5.2 Limitations

A notable limitation of our study concerns the small sample size. Sweden is, despite the relatively large share of green bond issuances, a small field to study. To illustrate, the total number of green SEK bonds issued in Sweden is 87, compared with 326 bonds if we would have chosen bonds issued in the entire EU denominated in all currencies (according to the data received by CBI). However, limiting the scope to Sweden eliminates currency, country and potential tax treatment effects. This advantage enables enhanced isolation of the *green effect* and stands in contrast with for example Zerbib (2017), whose results are likely to be biased by omitted country effects.

Secondly, the use of ASW slightly decreases the available data observations in comparison to if we would have used yield to maturity. Missing observations is a consideration for the statistically inference of our study (Wooldridge, 2003), since the available data dictates the sample size. Yet, as discussed in subsection 2.2.1, there are outweighing benefits of using ASW: it better captures the dynamical changes in the underlying risk-free rate and constitutes a measurable way to include floating coupon bonds.

As of liquidity measures, we discuss in the previous section the limitations related to the use of only one liquidity measure. The justification of the bid-ask spread is based on the frequent and acknowledged use in relevant previous papers, see subsection 2.2.3.

Regarding our statistical regression methods, we recognize limitations with the basic OLS regressions, with and without time fixed effects. Not adjusting for serial correlation represents a source of error. Therefore, we choose to complement with Prais-Winsten adjusted for serial correlation. Still, there are limitations with this approach. If we presume that our variables do not completely explain the yield variance, the method become less reliable (i.e. *omitted variable bias*)

(Wooldridge, 2003). A more ideal method would have been *matching*: studying yield difference between bonds with the exact same characteristics except for the green classification. However, as discussed in section 3.6, there are not yet enough observations to employ this method. As a compromise, we use the Oaxaca-Blinder decomposition where the yield difference is decomposed in an explained (by data characteristics) and an unexplained part. However, the Oaxaca-Blinder method cannot completely erase the possibility that there are unobserved variables that might bias the results. Such variables might for example be details about the specific project financed. Those variables are however hard to control for in data and should be considered as limitations of any models.

## 5.3 Contribution

The contribution of our study is twofold. It confirms the existence of a negative green yield premium in the secondary market, which has only been investigated by a few other authors before. The yield discrepancy confirms the relevance of the research field and highlights the need for future research on green bond pricing.

Secondly, the findings have implications for stakeholders in the Swedish bond market. Recalling the Swedish government's proposal including green bond subsidies and a green sovereign bond, the negative green premium needs to be considered in such policymaking. If the negative yield premium is the result of a supply-demand gap, then this needs to be taken into account in the discussion of how to most effectively stimulate the market development. An investment subsidy on green bonds might not be the best option.

Bond investors face a dilemma, whether to maximize yield or invest sustainably. Larger institutional investors need to address if they are willing to sacrifice yield when buying green bonds. It is of interest for private investors and citizens being a part of the Swedish pension system to know how their asset managers, pension funds and insurance companies handle this dilemma. The green bond expensiveness also sheds light on the importance of a functioning green bond classification system. The process and the follow-up reports when labelling bonds green need to be rigorous and justifiable, enabling investors to see if they really pursue the environmental impact they are paying for. The development of globally standardized principles and improved ways of measuring the environmental impact of each bond are areas that we believe will play an important role in improving the system's transparency towards both private and institutional investors.

# VI. Conclusion

Being a role model in developing the green bond market and having an ongoing political debate on the subject, highlights the relevance of studying the Swedish green bond market. Constituting the seventh largest source of green bonds worldwide yet having the same currency and same tax treatments for all bonds makes Sweden an appropriate market to study.

Based on our selected method, we obtain a sample of 32 green and 303 conventional bonds over the time period 2013-2017, resulting in a panel data set of 111,980 observations. Our paper finds that there is on average a negative and statistically significant yield difference between green and brown bonds. This is in line with previous studies by Karpf and Mandel (2018) and Zerbib (2017) and holds true for multiple regression methods, including the Oaxaca-Blinder decomposition. The latter decomposes the effects of data characteristic differences between green and brown bonds and provides further confirmation of a negative yield premium based on the green classification alone. The yield difference is best approximated to 12.9 basis points lower for green bonds than brown for the whole period.

Our further examination of the premium studies the liquidity effect on yield for green and brown bonds. We obtain indications of a potential green liquidity effect but do not find an overall robust relationship between bid-ask spread and yield. We recognize the use of several liquidity measures as a potential source of improvement.

We can only speculate about the reasons for the negative green yield premium and the ambiguous liquidity effect. Potential explanations include a possible gap between strong demand and a relatively small supply. The finding uncovers a dilemma for bond investors, to maximize yield or to invest green. However, the market is still in a phase of rapid growth and research in the field is limited. We therefore view the green bond market as an important topic for future research.

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# Appendix

## Appendix A - Complementary Tables

Table 7

Table showing rating scale translation with S&P Equivalent being the translated rating. The scale is based on a standardized approach published by the European Banking Authority (2006)

| S&P Equivalent | S&P Long Term | Moody's Long Term | Fitch | Bloomberg Default Risk Scale[28] |
|---|---|---|---|---|
| AAA | AAA | Aaa | AAA | IG1 |
| AA | AA+, AA, AA- | Aa1, Aa2, Aa3 | AA+, AA, AA- | IG2, IG3, IG4 |
| A | A+, A, A- | A1, A2, A3 | A+, A, A- | IG5, IG6, IG7 |
| BBB | BBB+, BBB, BBB- | Baa1, Baa2, Baa3 | BBB+, BBB, BBB- | IG8, IG9, IG10 |
| BB | BB+, BB, BB- | Ba1, Ba2, Ba3 | BB+, BB, BB- | HY1, HY2, HY3 |
| B+, B, B- and below | B+, B, B- and below | B1, B2, B3 and below | B+, B, B- and below | HY4, HY5, HY6 and below |

[28] Bloomberg Default Risk Scale used as a supplementary source when rating is missing. The translation is based on default risk information from Bloomberg and S&P Global

Table 8

Table showing complete results of the Oaxaca-Blinder Decomposition for the whole period (2013-2017) where endowments represents explained part and coefficients unexplained part. See section 4.1.3 for interpretation of the results and Appendix B for technical notes of the decomposition

| | (1)<br>overall | (2)<br>endowments | (3)<br>coefficients | (4)<br>interaction |
|---|---|---|---|---|
| Bid-Ask Spread | | 0.0183 | 0.758*** | -0.161*** |
| | | (0.0400) | (0.205) | (0.0440) |
| AA | | -0.0633** | 2.879*** | 0.788*** |
| | | (0.0253) | (0.114) | (0.0660) |
| A | | -2.978*** | 9.365*** | 5.589*** |
| | | (0.194) | (0.332) | (0.231) |
| BB or BBB | | 2.164*** | 19.38*** | -11.98*** |
| | | (0.188) | (0.479) | (0.391) |
| DTM | | 5.880*** | -17.85*** | -3.025*** |
| | | (0.163) | (0.492) | (0.110) |
| corporate | | 17.52*** | -15.06*** | -8.523*** |
| | | (0.451) | (0.664) | (0.391) |
| amount | | -7.238*** | 0.296** | 2.671** |
| | | (1.294) | (0.143) | (1.293) |
| floating | | 7.337*** | 7.337*** | -7.337*** |
| | | (0.177) | (0.177) | (0.177) |
| group_Brown | 61.25*** | | | |
| | (0.152) | | | |
| group_Green | 47.71*** | | | |
| | (0.319) | | | |
| difference | 13.54*** | | | |
| | (0.354) | | | |
| endowments | 22.64*** | | | |
| | (1.526) | | | |
| coefficients | 12.88*** | | | |
| | (0.407) | | | |
| interaction | -21.97*** | | | |
| | (1.534) | | | |
| Constant | | | 5.765*** | |
| | | | (0.705) | |
| Observations | 111,890 | 111,890 | 111,890 | 111,890 |

Table 9

Table showing autocorrelation-test for the original OLS regression

| Wooldridge test for autocorrelation in panel data |
|---|
| H0: no first-order autocorrelation |
| F( 1, 266) = 9.715 |
| Prob > F = 0.0020 |

Table 10

Table showing the original OLS regression with robust standard errors with different measures of bid-ask spread

| | (1) Monthly | (2) Daily | (3) Weekly | (4) Quarterly | (5) Yearly |
|---|---|---|---|---|---|
| Bond Type: Green/Brown | -3.678*** | -7.192*** | -5.971*** | -3.361*** | -3.486*** |
| | (-11.46) | (-9.31) | (-13.92) | (-11.20) | (-11.88) |
| Monthly Bid Ask Spread (bp) | 0.00645*** | | | | |
| | (5.40) | | | | |
| Credit Rating AA | 13.48*** | 12.39*** | 12.67*** | 12.88*** | 12.76*** |
| | (58.11) | (24.15) | (43.73) | (59.06) | (59.62) |
| Credit Rating A | 13.55*** | 15.61*** | 15.42*** | 13.25*** | 13.09*** |
| | (64.59) | (36.45) | (61.77) | (65.44) | (64.87) |
| Credit Rating BBB or BB | 56.05*** | 59.84*** | 59.76*** | 54.53*** | 54.24*** |
| | (71.34) | (39.30) | (64.83) | (72.10) | (72.77) |
| Days to Maturity | 0.0125*** | 0.0126*** | 0.0126*** | 0.0125*** | 0.0125*** |
| | (171.20) | (86.00) | (144.84) | (175.46) | (176.53) |
| Issuer Type: Corporate/Official | 28.68*** | 25.51*** | 26.15*** | 28.70*** | 28.53*** |
| | (127.54) | (54.48) | (96.60) | (132.25) | (132.61) |
| Issue Amount (SEKm) | -0.000716*** | -0.000710*** | -0.000711*** | -0.000713*** | -0.000713*** |
| | (-163.64) | (-77.69) | (-134.33) | (-162.67) | (-160.92) |
| Coupon Type: Floating/Fixed | -60.85*** | -39.71*** | -47.87*** | -63.91*** | -63.78*** |
| | (-61.95) | (-20.36) | (-41.35) | (-67.70) | (-67.94) |
| Daily Bid Ask Spread (bp) | | 0.00782** | | | |
| | | (3.05) | | | |
| Weekly Bid Ask Spread (bp) | | | 0.00857*** | | |
| | | | (6.07) | | |
| Quarterly Bid Ask Spread (bp) | | | | 0.00723*** | |
| | | | | (4.64) | |
| Yearly Bid Ask Spread (bp) | | | | | 0.00629** |
| | | | | | (2.71) |
| Observations | 111890 | 24016 | 73333 | 121534 | 124019 |
| Adjusted $R^2$ | 0.423 | 0.457 | 0.438 | 0.420 | 0.420 |

*t* statistics in parentheses
$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

Table 11

Table showing basic OLS regression with robust standard errors, presented for step-wise addition of explanatory variables

| | (1) Baseline | (2) Add Bid-Ask | (3) Add rating | (4) Add age | (5) Add corporate | (6) Add amount | (7) Add floating |
|---|---|---|---|---|---|---|---|
| Green | -38.22$^{***}$ | -38.47$^{***}$ | -17.09$^{***}$ | -14.46$^{***}$ | -7.673$^{***}$ | -11.63$^{***}$ | -3.678$^{***}$ |
| | (-55.14) | (-51.29) | (-45.34) | (-39.20) | (-19.68) | (-30.68) | (-11.46) |
| Bid Ask Spread (bp) | | -0.0287$^{***}$ | 0.0128$^{***}$ | 0.0142$^{***}$ | 0.0172$^{***}$ | 0.00670$^{***}$ | 0.00645$^{***}$ |
| | | (-4.12) | (9.94) | (11.98) | (15.49) | (5.56) | (5.40) |
| Credit Rating AA | | | 28.60$^{***}$ | 29.98$^{***}$ | 23.28$^{***}$ | 15.12$^{***}$ | 13.48$^{***}$ |
| | | | (92.57) | (100.09) | (93.99) | (65.33) | (58.11) |
| Credit Rating A | | | 39.20$^{***}$ | 40.42$^{***}$ | 27.36$^{***}$ | 15.00$^{***}$ | 13.55$^{***}$ |
| | | | (178.74) | (205.15) | (138.46) | (71.92) | (64.59) |
| Credit Rating BBB or BB | | | 78.98$^{***}$ | 82.56$^{***}$ | 68.04$^{***}$ | 54.81$^{***}$ | 56.05$^{***}$ |
| | | | (100.94) | (106.84) | (84.70) | (68.60) | (71.34) |
| Days to Maturity | | | | 0.0124$^{***}$ | 0.0121$^{***}$ | 0.0125$^{***}$ | 0.0125$^{***}$ |
| | | | | (145.35) | (150.10) | (169.39) | (171.20) |
| Corporate | | | | | 24.40$^{***}$ | 28.64$^{***}$ | 28.68$^{***}$ |
| | | | | | (96.85) | (124.55) | (127.54) |
| Amount (SEKm) | | | | | | -0.000710$^{***}$ | -0.000716$^{***}$ |
| | | | | | | (-162.64) | (-163.64) |
| Floating | | | | | | | -60.85$^{***}$ |
| | | | | | | | (-61.95) |
| Observations | 152461 | 133531 | 112548 | 112548 | 112548 | 111890 | 111890 |
| Adjusted $R^2$ | 0.002 | 0.002 | 0.243 | 0.318 | 0.345 | 0.400 | 0.423 |

*t* statistics in parentheses
$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

## Appendix B - Oaxaca-Blinder decomposition (threefold)

There are two groups A (brown) and B (green), a dependent variable Y (ASW) and a set of explanatory variables. The technical notes presented below are in a general form.

The problem to solve is how much of the mean outcome difference *(R)* that can be explained by the data characteristic difference and how much that cannot be explained:

$R = E(Y_A) - E(Y_B)$

where $E(Y)$ denotes the expected value of the dependent variable that comes from group differences in the explanatory variables.

Starting from a linear model, the mean outcome difference can be revisited as the deviation in the linear prediction at the group-specific means of the regressors:

$R = E(Y_A) - E(Y_B) = E(X_A)'\beta_A - E(X_B)'\beta_B$

where $X$ is a vector containing the explanatory variables' prediction and a constant, $\beta$contains the slope parameters and the intercept, and $\varepsilon_i$ is the error term. Assume $E(\beta') = \beta'$and $E(\varepsilon) = 0$

To separate the contribution of group differences in the explanatory variables, the decomposition rearranges the equation to:

$R = (E(X_A) - E(X_B))'\beta_B + E(X_B)'(\beta_A - \beta_B) + (E(X_A) - E(X_B))'(\beta_A - \beta_B)$

This is a threefold decomposition and the total difference is split up into three parts:

$R = E + C + I$

The first component represents the endowment effect *(E).* It is the difference that can be explained by differences in data characteristics in the explanatory variables for the two groups:

$E = (E(Y_A) - E(Y_B))'\beta_B$

The second part amounts to the coefficient effect *(C).* It is the contribution of differences in the coefficients, including differences in the intercept. It can be interpreted as the unexplained part of the difference:

$C = E(X_B)'(\beta_A - \beta_B)$

The third term is the interaction effect, which accounts for simultaneous differences in both $E$ and $C$ in the two groups:

$I = (E(X_A) - E(X_B))'(\beta_A - \beta_B)$

Let $\hat{\beta}_A$ and $\hat{\beta}_B$ be the least squares estimates for $\beta_A$ and $\beta_B$ provided separately from the two group-specific datasets. Use the group average $\bar{X}_A$ and $\bar{X}_B$ as estimates for $E(X_A)$ and $E(X_B)$. The decompositions are then computed as following:

$$\hat{R} = \bar{Y}_A - \bar{Y}_B = (\bar{X}_A - \bar{X}_B)'\hat{\beta}_B + \bar{X}_B'(\hat{\beta}_A - \hat{\beta}_B) + (\bar{X}_A - \bar{X}_B)'(\hat{\beta}_A - \hat{\beta}_B)$$

$$\hat{R} = \bar{Y}_A - \bar{Y}_B = (\bar{X}_A - \bar{X}_B)'\hat{\beta}_A + \bar{X}_A'(\hat{\beta}_A - \hat{\beta}_B) + (\bar{X}_A - \bar{X}_B)'(\hat{\beta}_A - \hat{\beta}_B)$$

*Interpretation*

The **difference** is the average difference between ASW for brown and ASW for green bonds. A positive difference denotes that green bonds on average trade at lower yields than brown bonds. The **endowment** is the difference in mean that can be explained by data characteristics captured by the explanatory variables, e.g. if green bonds on average have lower rating, and lower rating is estimated to yield a lower ASW, then the decomposition also expects the total difference to be greater. The **coefficient** is the part of the difference that cannot be explained by mean differences in the explanatory variable between the two groups. The **interaction** is the term that measures the simultaneous effect of differences in endowments and coefficients.

The decomposition procedure outlined above is based on the technical notes provided by Jann (2008) in *A Stata implementation of the Blinder-Oaxaca decomposition.* The complete results of the Oaxaca-Blinder decomposition for the whole period are presented in **Table 8** in Appendix A.