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Keen for Green

A Study of Pricing in the Secondary Green Bond Market

Authors:

Rickard Anderkrans

Patrik Johannesson

Supervisors:

Anders Vilhelmsson

Zahra Hashemzadeh

Thesis Summary

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Authors	Rickard Anderkrans, Patrik Johannesson
Advisors	Anders Vilhelmsson, Zahra Hashemzadeh
Key words	Green bonds, Panel data, Issuer fixed effects regression, Capital asset pricing model, Investor preferences
Purpose	Our aim is to study if the structural shifts in investor preferences have created a negative risk premium in the pricing of green bonds.
Methodology	The quantitative methodological approach utilises panel data with a sample of green bonds and their conventional counterpart from the same issuer. We conduct OLS and issuer fixed effect regressions with added robustness checks to stress-test liquidity variables.
Theoretical perspectives	This study finds its theoretical foundation in the capital asset pricing model (CAPM), aiming to establish whether investor preferences toward nonpecuniary factors such as sustainability bring investor utility, challenging the original CAPM assumptions.
Empirical foundation	We use a sample of 1,795 unique bonds of which 397 represent green bonds and 1,398 represent conventional bonds from 172 unique issuers. The included green bonds are aligned with the Green Bond Principles and the study period covers 2014-2018.
Conclusions	We find an average significant negative green bond premium of approximately -4 to -5 bps. We also find that the green bond premium is not stable over time, indicating that the attractiveness of the asset class increased significantly between 2014 and 2018. We found the average green premium to be -16.74 and -5.88 bps during 2017 and 2018 respectively.

Abstract

The emerging green bond market is a novel research area with only a few studies being published in recent years. The increase in interest from issuers, investors, and academia shows the clear need for further investigation of the pricing dynamics affecting the green bond market. This study finds its theoretical foundation in the capital asset pricing model (CAPM), aiming to establish whether investor preferences toward nonpecuniary factors such as sustainability bring investor utility, challenging the original CAPM assumptions. If so, investors would demand lower financial returns as they find utility in the fact that green bonds cater to their sustainability preferences. We study the secondary green bond markets between 2014 and 2018 to investigate if there exists a negative yield premium when comparing a sample of green bonds with their non-green counterparts. The quantitative methodological approach includes OLS and issuer fixed effect regressions. Our differentiated sampling process allows us to construct the largest sample of green bonds compliant with the Green Bond Principles to date. We conclude that there exists a negative green bond premium of -4 to -5 basis points. Our findings also indicate that the green bond premium is not stable over time, with significantly negative yield premiums in 2017 and 2018. Our results remain robust after additional controls for potential liquidity differences, indicating strength in the statistical inferences.

Keywords: *Green bonds, Panel data, Issuer fixed effects regression, Capital asset pricing model, Investor preference*

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Rickard Anderkrans

Patrik Johannesson

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1. Introduction

The need for alignment between the financial markets and the battle for sustainability has perhaps never been greater as the drive towards achieving the goals stipulated by the Paris agreement and the UN Sustainable Development Goals accelerates. According to the OECD (2017), the yearly global investment needs in infrastructure alone is USD 6.9 trillion for the next 15 years in order to be consistent with the Paris Agreement. As regulatory clampdowns[1] reduce banks' ability to fund sustainable investments needs, many initiatives have been launched to redirect assets toward green investments while pushing institutional investors to integrate sustainability in their investment mandates. In the absence of a massive carbon tax scheme, green bonds have emerged as an important funding vehicle that encourages institutional investors portfolio allocation towards sustainable investments.

The green bond market has seen rapid development since the first issuance and saw a total issuance of USD 183 bn in 2018. The increase in issuance is primarily driven by the financial and corporate sector within Europe and the United States. Furthermore, green bonds are the most used sustainable debt financing instruments worldwide with sustainability-linked loans as the second most common debt issuance (SEB, 2019). Green financing solutions are expected to increase even further in the short to medium term with an expected issuance of USD 210-240 bn in 2019. According to SEB (2019), this puts further pressure on developing a framework and standardising the process to spur capital allocation towards the market.

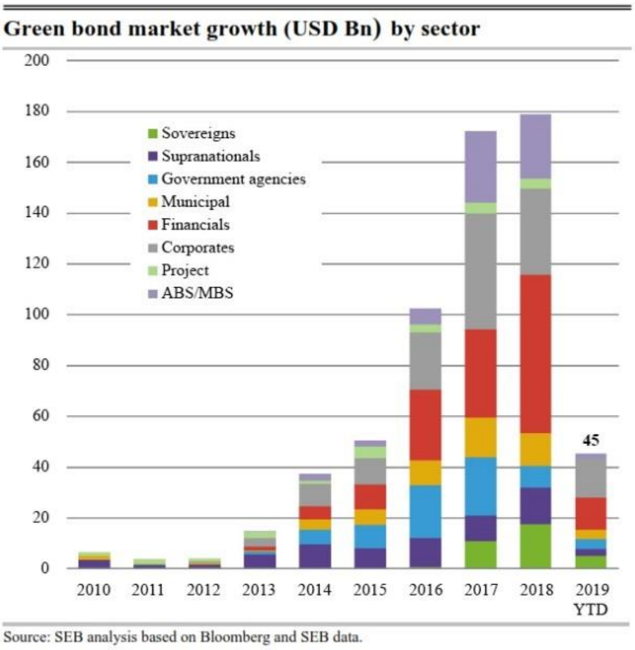

Figure 1. Growth in the green bond market accelerated in 2014.

[1] E.g. The Basel III framework and the Capital Requirements Directive (CRD IV)

Green bonds are a relatively new financial instrument where the first climate focused bond was issued by the European Investment Bank in 2007. The World Bank (2015) defines a green bond as a fixed income product that offers investors the chance to participate in financing green projects aimed at mitigating negative climate effects on society and support climate-related environmental projects.

Understanding the characteristics of green bonds and other sustainable financing solutions are of extreme importance when the world is struggling to transition from a capital and production system that is driven by fossil-fuelled energy sources to more sustainable energy sources and a circular economy. The supply and demand dynamics of the green bond markets are currently skewed, with demand surpassing supply as investors' scramble to meet the ever-expanding ESG[2] and SRI[3] investment mandates (Wulandari et al. 2018). These dynamics are characterised by a backdrop of rapid regulatory developments, investor preferences and a global push towards sustainability. This has raised the question of whether green bonds are priced on the same terms as other fixed-income instruments, even if their fundamental characteristics are the same.

The prevailing green bond market backdrop leads us to question some of the assumptions underlying the standard asset pricing models, e.g. the capital asset pricing model (CAPM). According to these types of models, there should be no difference in pricing between a conventional bond[4] and a green labelled bond given their identical characteristics, ceteris paribus. However, Fama and French (2007) argue that investor preferences can be a key determinant of asset pricing, beyond a strict focus on the probability distributions of future asset payoffs. Baker et al. (2018) presents a modified CAPM, hypothesising that securities with positive environmental scores (such as green bonds) have lower expected returns. This notion contrasts the assumption of strictly return-focused investors, suggesting that investors can find utility in nonpecuniary parameters such as sustainability factors. Our aim is to study if the structural shifts in investor preferences have created a negative risk premium in the pricing of green bonds, and if such is the case, calling the utility function of the original CAPM into question. This study is the first independent test of the modified CAPM hypothesis presented

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[2] Environmental Social and Governance. How a firm's products and services contribute to sustainable development and how it manages its own operations to minimise negative impact through risk management. Have development as a factor in assessing the risk of an investment through the firm's impact on the environment and society (Harnett, 2018).

[3] Sustainable Responsible Investing. Investment strategy that seeks financial return and sustainable positive impact.

[4] Conventional bond is referred to as a non-green labelled bond, however it does not mean that its proceeds cannot be earmarked for "green" projects.

by Baker et al. (2018). Therefore, testing the hypothesis on a new dataset with a more heterogenic sample will act as a complement to their study and theoretical approach.

Empirical studies of the pricing of green bonds are scarce and suffer from a lack of robustness due to small sample sizes, imperfect controls for liquidity and a limited scope of analysis. However, a range of studies suggest that both firms and investors stand to benefit from assets with strong sustainability metrics (E.g., Konar and Cohen, 2001; Derwall et al. 2005; Kempf and Osthoff, 2007; Statman and Glushkov, 2009; El Ghoul et al. 2011; Dhaliwal, Tsang and Yang 2011). Perhaps the most well-cited study of the secondary green bond market by Zerbib (2019) found support for a small, albeit statistically significant, negative green bond premium. Yet we would argue that the methodology used in Zerbib's (2019) study unnecessarily restricts the potential sample size and lack robustness in terms of liquidity controls. As opposed to Zerbib (2019), we do not utilise the method of maturity matching through creating synthetic conventional bonds[5] as it restricts the sample and essentially reverse-engineers the effect from a linear regression. Firstly, this method excludes green bonds with only one conventional neighbour while also excluding the possibility of adding more conventional bonds from the same issuer and any bonds with a maturity differing two years, thus reducing the sample size and robustness of the results. Secondly, if we assume linearity, an appropriately specified issuer fixed effects regression model handles maturity biases while increasing panel data variability, making the step of creating synthetic bonds redundant. We propose a panel regression to build a robust sample of green and conventional bonds from the same issuers.

To the best of our knowledge only working papers by Baker et al. (2018) and Wulandari et al. (2018) has used a similar method to analyse green bond pricing and liquidity. However, Baker et al. (2018) only studies the primary market with a homogenous sample of US municipal green bonds, and Wulandari et al. (2018) liquidity study utilises a narrow sample of 64 green and 54 conventional bonds. Our study allows for a more generalisable and rigorous test of the green bond premium in the secondary green bond markets as found by Zerbib (2019), to find evidence if investors find utility in the green label of such instruments. We use a sample of 1,795 unique bonds of which 397 represent green bonds and 1,398 represent conventional bonds from 172 unique issuers. Using five different

[5] "To build this synthetic conventional bond, for each green bond, we first search for the two conventional bonds with the closest maturity from the same issuer and having exactly the same characteristics.... We then interpolate (or extrapolate) the two conventional bonds' yields linearly at the green bond maturity date to obtain a synthetic conventional bond yield" (Zerbib, 2019)

multivariable regression specifications, we aim to disentangle the green premium in terms of yield spreads while also examining pricing differences over time. We find that during the years 2014 and 2018 there exists an average negative green bond premium of -4 to -5 basis points (bps). The negative green bond premium remains robust even after performing liquidity stress tests on the models. Our result also indicate that this negative green bond premium is not stable over time, with significantly negative yield premium in 2017 and 2018 (-16.74, -5.88 bps respectively).

Our primary contribution to this novel and fast-growing research area is that we conduct the most comprehensive study to date on the green bond market aligned with the strict scope of the Green Bond Principles (GBP). We introduce a wider range of liquidity controls to establish if the green bond premium is not just a result from differences in liquidity. We also investigate additional factors that could impact yield spreads such as the ECB asset-purchase program[6] and the impact of institutional issuers with the aim to examine how these factors contribute to green bond pricing. Our larger sample also allow us to substantially mitigate concerns about unobserved heterogeneity by using issuer fixed effects. The findings in our study are of use for both investors and firms in understanding the pricing dynamics of this novel asset class, while also providing empirical support for the very limited green bond literature.

[6] The programme came as an incentive after the financial crisis of 2008 to stimulate the economy, increasing inflation and sending signals of lowering cost of debts by buying corporate and public securities (ECB, 2018).

2. Literature Review and Theoretical Framework

2.1 Green Bonds

Green bonds started to gain traction following the Copenhagen Accord[7] in 2009 as one way to finance the transition to a low-carbon economy (OECD, 2015). It became clear that the financial markets would have to become a key vehicle for the allocation and mobilisation of investments for green projects. The Accord posited that the best strategy to increase such investments was to develop financial instruments that investors deem adoptable and value creating while providing exposure to a sustainable asset base. Based on these considerations, green bonds were created (Bachelet, Becchetti and Manfredonia, 2019). Green bonds have identical fundamental characteristics as conventional bonds and provide the same benefits for the issuer such as diversifying financing sources while also catering to investors that demand SRI and ESG as part of their investment criteria. It also creates a tool to raise awareness about different climate aspects affecting firms' business models and starts a dialogue that could increase long-term value, thus creating a strong signalling value (World Bank, 2015). Bachelet et al. (2019) argues that firms are starting to see increased economic benefits through sustainability efforts and not merely environmental exposure from a risk management perspective, thereby allowing for sustainability and stakeholder value maximisation to coexist and enhance one another.

The key differentiator between a conventional bond and a green bond is the due diligence process where the issuer is expected to comply with certain frameworks and obligations throughout the bond's lifetime. The proceeds are thus expected to finance or refinance, in part or in full, new or existing projects that generate environmental benefits for society. There is currently no universal standard for a compliance framework, and depending on the issuer, several frameworks are present to certify the "greenness" of the bond. Hence, green bond authenticity is subject to asymmetric information stemming from its 'invisible' characteristics (Bachelet et al. 2019). However, the most frequently used initiative on a global level is the GBP which are voluntary guidelines that promote integrity and transparency in the development of the market by clarifying the approach for issuance of a green bond. The GBP also recommends the issuer to use a third-party review to certify that the issuer is compliant with the relevant guidelines of the applied framework which mitigates asymmetric information between issuers and investors. Given the recent influence of the GBP, Zerbib (2019) argues that green bonds have become a standardised asset class which provides issuers and investors

[7] United Nations climate change conference in Copenhagen 2009. Voluntary agreement between nations pledging to reduce carbon emission and report their changes (United Nations, 2009).

with enough cash flow and collateral, suitable for the established investment mandates of large institutional investors.

Despite a rapid demand growth, the supply of green bonds is hampered by three factors: (1) a lack of a universal classification system such as the GBP that is in accordance with market-based frameworks (Cochu et al. 2016; Wulandari et al. 2018), (2) inadequate fiscal incentives for green investments (Zerbib, 2019) and (3) shortage of compliant "purely" green investment projects. The supply discussion could in a broader market-based sense be categorised into two main drivers, which Katugampola (2018) refers to as push and pull factors. The push factors include regulators and policymakers supporting the development of green bonds while pull factors include increasing demand, both from investors and issuers. An important push factor is the lack of a universal classification system, which might cause opacity on the definition of "green" bonds, making issuers subject to considerable additional transaction costs relating to external reviewers and compliance, both pre- and post-green bond issuance (Katugampola, 2018; Wulandari et al. 2018). This reduces the incentives for issuers to consider green bonds in place of conventional bonds, especially given the low opportunity cost in the prevailing low-interest rate environment. On the other hand, Katugampola (2018) argues that the development of green bonds is spurred by broadening of the market. New issuers are entering, established market players are refinancing and the fixed-income market is continually strengthening its position as the natural source for environmental financing. The fixed income market is surpassing the equity market as a channel to communicate sustainability initiatives, allowing organisations to efficiently raise financing and highlight their sustainability strategies while partnering with investors for the longer term.

2.1.1 Certification

As the market matures, investors will demand more information and transparency from issuers to reduce asymmetric information between the parties. For the green bond to gain its unique characteristics it needs to comply with a specific framework and preferably be validated by an independent third party to gain investor confidence. As a result, third-party agencies have started to evaluate the "greenness" of bonds in addition to variables such as maturity, coupon, price and credit quality. It is therefore imperative to maintain a rigorous system where the risk of false or misleading labelling of green bonds is minimised to secure investors' confidence in the system. Parallels can be drawn to Akerlof's (1970) seminal article on the market for lemons and adverse selection issues. Labelling bonds as green can mitigate adverse selection problems as the costly signalling through certification increases the chance of reaching a separating pricing equilibrium.

Even if certifying a bond as green as opposed to a conventional issuance is associated with additional costs, it could reduce information asymmetry between issuers and investors, potentially providing issuers with improved pricing terms and investors with improved client attraction. Bachelet et al. (2019) argue that the lack of congruence in the labelling of green bonds increases the risks for 'greenwashing', where companies claim to issue green bonds that are not compliant with the conventional frameworks, thus diminishing investors' trust in the green market. Regulation and framework congruency will therefore be key factors in improving the certification value of a green bond label.

2.1.2 The Green Bond Market Going Forward

In March 2018, the European Commission adopted the action plan for financing sustainable growth ("Action Plan") (European Commission, 2018). The Action Plan is aimed to connect the European and global economy for the benefit of the planet and society as well as produce an EU taxonomy to provide more legal certainty. The Action plan featured three key goals. (1) Reorient capital flows towards sustainable investment to achieve sustainable and inclusive growth. (2) Manage financial risks stemming from climate change, resource depletion, environmental degradation and social issues. (3) Foster transparency and long-termism in financial and economic activity.

One of the key areas addressed in the Action Plan relates to green bonds. The European Commission (2018) aims to produce a standard which will be accessible to market participants with the aim to channel more investments into green projects and constitute a basis for the development of reliable certification of green financial products. This is aimed to be implemented in Q2/Q3 of 2019 when the technical expert group set up in 2018 will present a report on how to build a green bond standard. Furthermore, the European Commission (2018) will increase demands on compliance for green bond issuers in terms of channelling more information towards investors. Once the EU taxonomy is adopted, the Commission will also explore the use of the EU Ecolabel frameworks to be adapted to the green bond practice. Evidence also suggests that asset managers and institutional investors do not systematically account for SRI and ESG factors, thereby not giving end investors the full disclosure they need to make investment decisions. The European Commission (2018) therefore aims to explicitly require asset managers and institutional investors to integrate SRI and ESG factors in the investment decision process and increase transparency on how they integrate such factors in the decision process.

2.2 Corporate Social Performance Impact on Firms

The foundation of the academic debate on firm's social responsibility finds its roots in the contrasting views of the shareholder theory presented by Friedman (1970) and the stakeholder theory introduced by Freeman (1984). For many years the Friedman doctrine, promoting purely shareholder-serving corporate objectives, stood fairly unchallenged in corporate governance focused literature. However, Freeman (1984) introduced winds of change to the discussion, effectively birthing the concept of what we now commonly refer to as corporate social responsibility ("CSR")[8] into the realm of financial academia. The debate of whether a firm's sole objective should be to create shareholder value or whether a more holistic stakeholder perspective should be promoted is very much alive, however, a growing body of literature supports a convergence between these concepts (E.g., Konar and Cohen, 2001; Derwall et al. 2005; Kempf and Osthoff, 2007; Statman and Glushkov, 2009; El Ghoul et al. 2011; Dhaliwal et al. 2011). The societal shift towards sustainability created a seedbed for growth of a rather novel strand of research within the financial literature, focusing on corporate social performance ("CSP")[9] and its impact on firms and the financial markets. Although no consensus has been reached, most of the published articles indicate a positive relationship between CSP and firms' financial performance.

A range of studies has found that strong CSP, especially as it pertains to low environmental impact, relates positively to equity returns (Konar and Cohen, 2001; Derwall et al. 2005; Kempf and Osthoff, 2007; Statman and Glushkov, 2009). Similar relationships have been found as it relates to the cost of equity capital (El Ghoul et al. 2011; Dhaliwal et al. 2011). Interestingly, studies by Heinkel, Kraus, and Zechner, (2001), Sharfman and Fernando (2008) and Chava (2014) all found that a low environmental impact specifically lowers cost of equity capital, suggesting a negative equity risk-premium. Although these findings are not axiomatically applicable to the bond markets, it shows a clear trend in investor preference towards socially and environmentally sustainable alternatives. These societal and investor

[8] CSR is a broad concept that addresses various topics such as human rights, corporate governance, health and safety, environmental effects and contribution to economic development. Regardless of the definition of the term, the purpose of CSR is to drive corporations to change towards sustainability. (Sheehy, 2014)

[9] While firms invest in CSR initiatives, CSP, as the measure of *firms' cumulative historical social performance relative to competition*, is what is rewarded by stakeholders, thus, creating a clearer link to financial performance (Luo and Bhattacharya, 2009).

trends naturally extend to the bond markets and raise the question of whether CSR-activities could reduce overall risk-levels and thus impacting bond yields.

2.3 CSP and Bond Yields

The academic literature studying the relationship between CSP and corporate bond yields have not established consensus results. In their cross-national pre-crisis study of 332 firms from 2005 until 2009, Magnanelli and Izzo (2017) found a positive relationship between CSP and cost of financial debt. Their findings align with shareholder theory, indicating that CSR is not a value-enhancer or driver of reduced risk, but rather a wasteful expense with notable opportunity costs. In his study of 498 European bonds, observed between 2004 and 2007, Menz (2010) found that the bond risk premium for socially responsible firms was higher than non-socially responsible firms. His, albeit weak, significant findings suggest that CSR has not yet been incorporated into the pricing of corporate bonds. Adding to the ambiguity, Sharfman and Fernando (2008) found that firms with better environmental risk management have a higher cost of debt, but a reduced weighted average cost of capital. When studying a sample of 872 corporate bonds from 12 EMU countries between 2006 and 2012, Stellner, Klein and Zwergel (2015) found weak evidence that superior CSP results in systematically reduced credit risk.

On the other hand, a range of other authors finds significant support for a negative relationship between CSP and cost of debt. Sun and Cui (2014) linked CSP to lower firm default risk using a sample of 829 observations from 303 firms. Jiraporn et al. (2014) cross-national study of 2,516 firm-year observations from 1995 to 2007 found that CSR improves credit ratings, primarily basing their discussion on the risk-mitigating features of strong CSP. In their comprehensive study of 3,240 U.S. bonds issued by 742 firms between 1993 and 2008, Oikonomou, Brooks, and Pavelin (2014) find that superior CSP is rewarded with lower corporate bond yield spreads. Their findings indicate that higher levels of CSP can lead to improved credit quality and lower perceived credit risk. Extending the analysis of CSR and cost of debt financing to the Canadian markets with a sample of 1,632 bonds from 1986 to 2014, Ghouma, Ben-Nasr, and Yan (2018) find that firms with superior corporate governance structures benefit from lower bond yield spreads. Huang, Hu and Zhu (2018) made similar findings on the Chinese markets between 2011 and 2015, indicating that there exists a negative relationship between CSR and yield spreads. The authors argue that CSR plays a significant role in reducing the risk premium of corporate bonds through an insurance-like effect.

Even though the abovementioned findings diverge, there seems to be a growing trend in the more recent studies indicating that superior CSP is rewarded by the bond markets while also reducing overall firm risk. However, the analysis of green bond prices builds on the use of proceeds as opposed to the studies focusing on the CSP of the issuing entity. Despite the strong growth trajectory of green bonds, studies of the asset class have yet to gain a solid footing within academic literature and have yielded mixed findings. Most published studies to date are conducted by financial institutions. HSBC (2016), Ehlers and Packer (2017) and Climate Bonds Initiative (2016) focus on the yield differential between green and conventional bonds at issuance, with small samples constituting of 30, 21 and 14 green and conventional bond pairs. HSBC (2016) and Climate Bonds Initiative (2017) fails to establish a significant difference in the primary market, indicating that investors are unwilling to pay a premium for green bonds at issuance.

On the other hand, Ehlers and Packer (2017) study of 21 Euro- and USD-denominated bonds issued between 2014 and 2017 found an average negative premium of 18 bps in the primary markets. Barclays (2015) and Zerbib (2019) study the yield difference on the secondary market. Barclays (2015) report finds a significantly average negative green premium of 17 bps between early 2014 and mid-2015 for the multi-currency Global Credit Index, including both corporate and institutional issuers. Using a sample of 110 matched green bonds in the secondary market, Zerbib (2019) found support for an overall negative green bond premium of 2 bps, attributing this discrepancy to the excess demand for green bonds and an insufficiently large volume of bond issuances. He further adds that the credit rating and issuer type are key determinants for the magnitude of the premium. Karpf and Mandel (2018) investigate the yield term structure differential of green and conventional bonds in the US municipal bond market using a sample of 1,880 bonds. This sample falls outside of the strict GBP criteria, but the findings indicate an average negative green bond premium of 7.8 bps. Karpf and Mandel (2018) further argue that the credit quality of green municipal bonds has increased and that green bonds are becoming an increasingly attractive investment. Similar to Karpf and Mandel (2018), Baker et al. (2018) study the after-tax yields of municipal bonds on the US market between 2010 and 2016 by investigating if securities with positive environmental scores have lower expected returns and have more concentrated ownership. They find that green bonds are issued at a premium, with yields lower by several basis points and that the ownership is more concentrated. Only Barclays (2015), Karpf and Mandel (2018) and Zerbib (2019) incorporate controls for liquidity biases. Wulandari et al. (2018) studied how liquidity risk impacts the yield spread between a sample of 64 matched green bonds, finding that the liquidity risk has become negligible for green bonds in recent years as investor interest has grown.

2.5 The Capital Asset Pricing Model

The rationale behind the fundamentals of asset pricing is clear, preferably yielding fair values for both investors and issuers as markets constantly discount new information. Sharpe (1964) introduced the capital asset pricing model ("CAPM") which still stands as one of the most influential asset pricing models. A fundamental aspect of the CAPM relates to the concepts of systematic and idiosyncratic risk, where the model stipulates that investors can eliminate their exposure to systematic risk through portfolio diversification, thus investors will only be compensated for idiosyncratic risk-taking. This refers to the risk premium, i.e. the return in excess of the risk-free rate of return. The risk premium could, therefore, be equated to the utility investors find from holding risky assets. Historically, investor utility has been viewed as being equivalent to financial compensation. However, as previously discussed a growing body of literature, such as Fama and French (2007), are suggesting a link between nonpecuniary factors and investor utility driven by a shift in investor preferences.

The original CAPM suggests that there should be no difference in the pricing of idiosyncratic risk between green and conventional bonds, ceteris paribus, given the identical fundamental characteristics of the asset classes. Investors should by extension expect identical financial returns for both asset classes. However, if we introduce the concept of nonpecuniary investor preferences such as environmental sustainability, it could be argued that these types of investors are willing to accept a lower financial return if they receive adequate utility from the 'environmental compensation' from the asset. Baker et al. (2018) applies these arguments to green bond pricing and hypothesises that securities such as green bonds have lower expected returns than its conventional counterpart. Thus, arguing that the CAPM needs to be revised to capture the effect of nonpecuniary factors on expected returns.

2.6 Liquidity

The notion that investors demand a liquidity premium for illiquid securities have reached consensus in the academic field and finds its origins in Amihud and Mendelson's (1986) seminal study. Additionally, Boudoukh and Whitelaw (1993), Vayanos (1998) and Lo, Mamaysky and Wang (2004) argue that the costs of liquidity inhibit the frequency of trading and transaction costs cause liquidity differences between securities. As such, illiquid securities have higher expected return than liquid securities since investors continuously demand an ex-ante risk premium because they cannot hedge this risk. As a result, Chen, Lesmond and Wei (2007) establish that bonds with the same promised cash flows, but are less liquid will trade less frequently, realise lower prices, and exhibit higher yield spreads which indicate that liquidity is expected to be priced in yield spreads.

As the green bond market is currently skewed with excess demand compared to supply, it could be argued that the green bond market should be illiquid from a perspective of an investor that currently is not an owner of a green bond and liquid for an investor that currently owns a green bond. The effects of liquidity premiums are especially important as it relates to the green bond market given the comparatively low volumes and supply shortage of green bonds (Wulandari et al. 2018). Therefore, studies of green bond yields need to include adequate controls for liquidity, which has been one of the primary flaws in previous green bond literature. The green bond liquidity study of Wulandari et al. (2018) is narrow in its scope from a sample perspective and does not represent a generalisable sample of the population of green bonds. Furthermore, they apply the LOT-measure which is mainly applicable to corporate bonds. Other studies such as Zerbib (2019) only uses the bid-ask liquidity measure on a similar sample size as Wulandari et al. (2018) which further leaves room for additional research of the effect of liquidity on the green bond market.

2.7 ECB Asset Purchase Programme

The emergence of green bonds coincided with the emergence of the ECB asset purchase programme, the largest central bank bond purchase program in the world, impacting liquidity and pricing across asset markets. To the best of our knowledge, no other study of green bonds has considered this variable in their analysis. Georgiadis and Gräb (2016) published a study of the ECB's announcement effects of the bond purchase programme. They found that the yield difference was quite muted with an average decrease in yield by less than 20 bps. Additionally, ECB themselves highlights the impact on green bonds specifically: "Overall, while the amount of green bonds held by the Eurosystem remains relatively small, evidence suggests that through its purchases the Eurosystem has reduced yields of green bonds and supported their issuance by non-financial corporations" (De Santis et al. 2018). This indicates that yield spreads are impacted by the ECB asset purchase programme. The ECB initiative applies to global assets and is not restricted to issuers from EMU member states. It is therefore vital to consider this factor in our models to increase the robustness of our findings.

3. Hypothesis Development

The two predominant factors to consider in asset pricing theory are risk and return. An increase in risk will effectively increase return as investors want to be compensated for the increased probability of capital loss. As a result, investors buying bonds with a higher likelihood of default will demand a higher return to compensate for taking on more risk. Thus, more risk averse investors will invest in bonds that are less likely to default and subsequently receive lower returns than their more risk seeking counterparts. However, when evaluating asset prices with a nonpecuniary clientele, investors are compensated not only by returns. According to Fama and French (2007), some investors are also compensated by holding securities aligning with their investor preferences and obtain additional utility by holding securities complying with their preferences, such as positive ESG factors.

To illustrate this, we use a similar CAPM-based rationale as Baker et al. (2018), where two investors, investor 1 and investor 2 faces an investment decision. Both individuals will have a common risk aversion factor of γ and common expectation for the securities return r and risk Σ. They choose a vector of portfolio weights w for each security in the investment decision. The difference however between the investors is that investor 2 also cares about ESG factors, which means that the investor will gain utility by having an ESG factor that is higher than 0 (e > 0). The two investors utility function is calculated using the following formula:

Investor 1: $$\max w_1' r - \frac{\gamma}{2} w_1' \Sigma w_1 \qquad (1)$$

Investor 2: $$\max w_2' r + w_2' e - \frac{\gamma}{2} w_2' \Sigma w_2 \qquad (2)$$

Furthermore, the two investors have capital of a_1 and a_2 respectively which yields a total market portfolio.

$$\frac{a_1}{a_1 + a_2} w_1 + \frac{a_2}{a_1 + a_2} w_2 = w_m \qquad (3)$$

Where w_m is the market portfolio with a vector of weights in each security of the two investors equal to its market values as a fraction of the total market value of all securities.

In the extreme case where the ESG factor e is always zero, a_2 will be equal to zero as investor 2 will not invest and thus only investor 1 will invest in the security which has no environmental preferences. Therefore, the market portfolio will be equal to:

$$w_1 = \frac{1}{\gamma} \Sigma^{-1} r = w_m \tag{4}$$

This equation can be used to compute the expected return of the market through the substitution of the inverse of risk aversion γ to the market Sharpe ratio, leading to the CAPM formula:

$$r = \frac{r_m}{\sigma_m^2} \Sigma w_m = \beta r_m \tag{5}$$

If we then add investor 2 who gain utility through the compliance of ESG factors, the portfolio weights of investor 2 would be calculated as:

$$w_2 = \frac{1}{\gamma} \Sigma^{-1} (r + e) \tag{6}$$

If we assume that the average environmental score is mean zero, we can make the same substitution for γ as we did before and thus we receive a remodified CAPM:

$$r = \frac{r_m}{\sigma_m^2} \Sigma w_m = \beta r_m - \frac{a_2}{a_1 + a_2} e \tag{7}$$

The example shows that the investor gain utility not only by return but also through an ESG factor higher than 0 which implies that the securities with positive ESG factors (such as green bonds) have a lower expected return compared to securities that do not fulfil the ESG factor through a lower β.

From this utility perspective, we would argue that theoretically there should be a negative yield premium between green bonds and conventional bonds. Green bonds compliant with the GBP can be considered possessing positive ESG scores, thus fulfilling the utility preferences of certain types of investors (investor type 2). As global investor demand for sustainable assets have increased rapidly in recent years, we hypothesise that this investor group has reached a critical mass of asset pricing impact. Subsequently, we test the following hypothesis:

H1: Green bonds have a negative yield premium compared to conventional bonds

The hypothesis is tested in terms of yield spreads, a widely used measure of bond pricing. The null hypothesis is that the yield spreads of our green bonds does not have a negative yield premium compared to their conventional counterparts. We reject the null hypothesis if the green bond yield spreads are lower than their conventional counterparts on a five percent statistical significance level. We fail to reject the null hypothesis if the yield spreads of our sampled green bonds are higher or equal compared to their conventional counterparts, or if the yield difference is not statistically significant on a five percent level. The hypothesis testing can be found under Section 5.3.

4. Methodology

4.1 Methodological Introduction

Most of the previous literature studying yield spreads base their empirical methods on structural models, that is, regressing a large number of issuer-specific and macroeconomic independent variables in appropriate model specifications (E.g. Blume, Keim and Patel, 1991; Campbell and Taksler, 2003; Chen et al. 2007). As indicated in our literature review, there is a lack of consensus as it relates to sustainability and bond yields, a discrepancy impacted by the variability in the regression model specifications. The methodological approach of this paper is aimed towards reducing liquidity biases and dependency on exogenous control variables by matching bonds with similar characteristics from the same issuer and comparing yield spreads of these bonds. Our sampling process and panel data methodology is inspired by Helwege, Huang and Wang (2013) and Baker et al. (2018) studying bond yields.

4.2 Delimitations

Due to the limited time horizon and scope of our thesis, paired with the many idiosyncratic variables impacting bond pricing, delimitations are necessary. Firstly, our study is limited to the secondary green bond market. Hence, our findings are likely of greater interest for bond investors rather than issuers, as it does not provide useful information regarding direct funding costs. However, issuers will find that a well-performing bond tends to secure refinancing at more favourable terms in the future. Including analysis of the primary markets would have broadened the statistical inference of the report and increase its generalisability.

Another delimitation concerns our sample, as we only include green bonds adhering with the strictest available green bond framework. The investable universe of fixed income products with a sustainability profile is far greater than bonds compliant with the GBP framework, such as social impact bonds, green loans and otherwise non-labelled green bonds. Including such products might provide a broader perspective on the utility function of sustainability in asset pricing, however, we see risks for sample inconsistencies reducing the quality of our statistical inferences. Additionally, our study only covers five years due to inadequate data availability and the novelty of the green bond label. Therefore, we excluded 2009 to 2013 as it would most likely yield less representative results given the recent developments of the market.

4.3 Sample

First, we construct our sample of green bonds, inspired by Zerbib (2019). Our sample universe initially builds on *labelled* green bonds issued between 31st December 2010 and 31st December 2018 from the Bloomberg Terminal, which derive their inclusion criteria from the

GBP. "Labelled green bonds are fixed income instruments for which the proceeds will be applied towards projects or activities that promote climate change mitigation or adaptation or other environmental sustainability purposes" (Bloomberg, 2015). This yields a list of 1,847 green bonds, primarily consisting of USD and EUR denominated investment grade bonds with varying microstructures. We remove bonds that do not have an initial rating from either Fitch, Moody's or S&P to control for credit risk through a third party. Furthermore, bonds with floating coupon rates are filtered out due to potential biases in spread measure, restricted data availability and incompatibility with our panel data methodology. Most floating-rate coupon bonds have quarterly coupons, implying that cash flow schedules only are available for three months, effectively making it impossible to calculate the relative value of such bonds over the period of this study. This narrows down the sample to 712 green bonds from 231 issuers.

Secondly, using the same characteristics of the abovementioned green bond sample as a reference, we construct our sample of conventional bonds. Our sample universe initially builds on fixed coupon conventional bonds with an initial credit rating, issued between 31st December 2010 and 31st December 2018 from the Bloomberg Terminal which yields a list of 670,772 bonds. Additionally, our search only includes bonds from the same issuers as our green bond sample with the same range of currencies. This leaves us with a list of 14,012 conventional bonds from the 231 issuers.

To create a manageable dataset when matching green bonds, we restrict the number of conventional bonds per green bond to a minimum of one and a maximum of ten[10]. When matching green and conventional bonds from the same issuer, two factors are considered, currency to mitigate interest rate biases and maturity date to mitigate liquidity biases. This creates unbalanced issuer-based panels with the same currency and conventional bonds with the closest available maturity date to the green bond. A small part of the labelled green bond universe is issued before 2014 and is not representative of the more diverse and liquid green bond market that has emerged in recent years. Therefore, we refrain from studying the period between 2010 and 2013 and remove bonds that matured before 2014[11]. Subsequently, we choose to base the study on data from a five-year period from 2014 to 2018. This yields a list of 1,921 bonds where 409 represent green bonds and 1,512 represents conventional bonds from 172 unique issuers.

[10] As an example of the sample size issues that could arise without this limitation, during the time period, Commonwealth Bank of Australia issued one green labelled bond and 621 conventional bonds.
[11] For example, a bond that is issued in 2011 but matures in the year 2013 will be excluded from the sample. However, a bond that was issued in 2011 but matures in the year 2017 will be included, but we choose to only study the year 2014, 2015, 2016 and 2017 for that specific bond, yielding four bond-year observations.

For the period 2014 - 2018, we collect yield spreads, bid prices, ask prices, high price, low price to calculate the liquidity measures for each bond. Modified duration is also collected to increase the explanatory degree of our model specifications. All price data is collected from Thomson Reuters Eikon via Linc, the Finance Society of Lund University. Furthermore, we add data using the Bloomberg Terminal to collect issue year, coupon, the amount issued, the amount issued in USD, country of domicile, sector and ECB asset purchase programme eligibility. In the case there is no yield spread data available for a green or conventional bond, we remove the bond. A removed conventional bond is replaced with the closest available bond based on the abovementioned criteria. When filtering out the green and conventional bonds using the criteria mentioned, we are left with a final sample of 1,795 bonds where 397 represents green bonds and 1,398 represents conventional bonds from 172 unique issuers. For a summarised list of the sample selection process, see Table 5 in the appendix.

We then construct bond-year observations for the observed period where a bond issued in 2014 will have 5 bond-year observations and a bond issued in 2018 will have one bond-year observation. This yields a total of 5,195 bond-year observations where 975 represents green bonds and 4,217 represents conventional bonds, as seen in Table 2 under Section 5.1. Tables 6 to 10 in the appendix provides a granular view of the sample composition. It becomes clear that green bonds tend to be issued in highly liquid developed currencies (such as EUR and USD) with larger average issue amounts than emerging market currencies. Green bonds tend to be investment grade, dominated by AAA-ratings due to a large amount of institutional issuance in developed countries. In terms of issuing sectors, the sample is dominated by Government agencies, Supranationals, and Financials (32.3%, 23.3%, and 20.6% respectively).

4.3.1 Selection Bias

Our panel dataset is unbalanced due to two primary reasons. Firstly, our sampling method allows pairing between 1 to 10 conventional bonds for every green bond from the same issuer. Secondly, the inclusion of bonds issued during or after 2014 and maturity before 2018. However, we believe that the attrition of bonds in our sample is random over time and therefore do not suffer from selection and survivorship bias through the exclusions of idiosyncratic factors stemming from issuance or maturity. This decreases risks for biased results, skewed higher or lower through selecting bonds strictly adapted to our arbitrary study period.

4.3.2 Sample Representativeness

Another key factor to consider is sample representativeness, i.e. the generalisability of our findings for the secondary green bond market. As illustrated in Figures 3 to 5 in the appendix, we compare the percentage distribution of credit ratings, issue currencies and sectors between our sample and the labelled green bond universe provided by Bloomberg. In terms of credit ratings, similarities are generally high with only minor deviations. Currency distributions, on the other hand, yield larger discrepancies, where our sample is overweight in EUR and USD denominated bonds. The skewness is a natural consequence of the bond markets being dominated by EUR and USD denominated bonds, providing superior access to appropriate conventional bonds in the sampling process. This can lead to less generalisable results for emerging market currencies, but more robust results for EUR and USD denominated bonds. Sector distribution is generally similar with minor deviations. In summary, we believe that the sample is representative of the current green bond market, strengthening the generalisability of our study.

4.4 Bond Pricing and Yield

Much like Zerbib (2019) and Baker et al. (2018), the first step in quantifying the green bond yield premium is to establish an appropriate dependent variable. Bonds are generally traded based on their prices but given the complex cash flow patterns and specific characteristics of bonds, they are compared in terms of yields (Choudhry 2004, p.20). Simply put, yield is the interest an owner receives from holding a bond and is calculated by dividing the coupon rate by the bond market price. For conventional bonds, yields are a well-researched topic with authors such as Blume et al. (1991), Campbell and Taksler (2003) and Chen et al. (2007) disentangling its determinants and how yield is impacted by exogenous factors. The yield is of great importance for both the issuing entity as it represents the funding cost, and fixed income investors as it constitutes the primary source of return. The same fundamentals apply for green bonds, and it is therefore a key aspect for both issuers and investors to understand the dynamics behind pricing and yield of this new and under-researched asset class. However, yield alone does not contain enough informational value to establish the green bond premium, as is explained in Section 4.6. The current bond yield is calculated by the following formula:

$$Y = \frac{C}{P} \tag{8}$$

where

P is the bond clean price (excluding any accrued interest)

C is the coupon rate

Y is the current yield of the bond

4.5 Yield to Maturity

The yield to maturity (YTM) is the most frequently used measure of return from holding a bond and considers the pattern of coupon payments, time until maturity and the capital gain (or loss) arising over the remaining life of the bond. The YTM is equivalent to the internal rate of return on the bond (Choudhry 2004, p.22). For a bond paying annual coupons, YTM is calculated by the following formula (the formula can be adjusted for different coupon frequencies such as semi-annual or quarterly coupons):

$$P_d = \sum_{n=1}^{N} \frac{C}{(1+rm)^n} + \frac{M}{(1+rm)^n} \tag{9}$$

where

P_d is the bond dirty price (including any accrued interest since the most recent coupon)

C is the coupon rate

M is the par or redemption payment (100)

rm is the annual yield to maturity (YTM)

n is the number of interest periods

Given the popularity of the YTM measurement as a method of comparing and analysing bonds, it would seem like an appropriate dependent variable for quantifying the green bond premium. However, there are three main disadvantages associated with using the YTM in relative valuation of bonds. The primary issue stems from the fundamental assumption of the YTM calculation, that the bond is held to maturity (Choudhry 2004, p.22). It is not reasonable to assume that all market participants are long-term investors, willing or able to hold bonds until maturity. This implies that the YTM concept tends to lack economic significance (Caks, 1977). Secondly, changes in the credit quality of the issuer over time impact the yield, and since most bondholders reinvest coupons at similar swap rates, realised return will be higher (or lower) than the YTM (Ibid.). Thirdly, the assumption of constant reinvestment rate until maturity implies a flat yield curve, which is not the case in most developed economies (Choudhry 2004, p.23). In conclusion, YTM does not provide an adequate bond valuation estimate, as we expect different reinvestment rates for different maturities, in line with the slope and shape of the yield curve. To mitigate the abovementioned issues, we require a measure which also considers a relative benchmark of comparable fixed income instruments of the highest available credit quality.

4.6 Yield Spread

In accordance with Zerbib (2019) and Wulandari et al. (2018) studies of green bond premia, this study utilises yield spreads as the dependent variable. Simply put, the yield spread is calculated as the yield of a bond subtracted from the yield of another bond. In this case, we follow the standard benchmarking of comparing the yields of the bonds in our sample and the appropriate "risk-free rate" of the same characteristics (i.e. a sovereign bond yield) to capture the effective risk premia rewarded to investors, making it an efficient tool to measure and compare bond valuation (Choudhry 2004, p.110). The yield spread thus constitutes the primary determinant of our estimation of a green bond premium as it compares to conventional bonds.

A potential bias that could arise from utilising the yield spreads in our study stems from benchmarking panels of green and conventional bonds with different sovereign bond yields. To mitigate such benchmark biases and ensure consistency, we collect mid-spread benchmark yields for all bonds and manually control that all panels calculate the spreads from the correct respective benchmark sovereign yield. For example, 10-year EUR denominated bonds follow the calculation below:

$$YS_S = Y_S - Y_{SB} \tag{10}$$

where

- Y_S is the yield of 10-year EUR denominated bond from sample
- Y_{SB} is the yield of 10-year EUR denominated sovereign bond
- YS_S is the yield spread 10-year EUR denominated bond from the sample

4.7 Green Bond Variable

The independent variable of our study is represented by a dummy variable indicating if a bond is *Green* or *Conventional.* As previously discussed, the current green bond market is suffering from a lack of a universal framework and definition. However, the most reputable green bond framework to date is established by the GBP, known to have the strictest inclusion criteria on the market today. A detailed overview of the database inclusion process is presented in Figure 6 in the appendix. This constitutes the foundation of which our green bond variable (*Green*) is defined, which we gather from The Bloomberg Terminal. By following the GBP framework, we assure consistency and robustness of our green bond sample.

4.8 Liquidity Proxies

Given previous discussions regarding liquidity impacting yield spreads and the similar financial characteristics between green and conventional bonds, we measure and compare the liquidity of both bond types in our sample to determine the liquidity effect on yield spreads. We investigate the bond-specific liquidity effects by calculating the bid-ask spread in accordance with Chen et al. (2007) and the Corwin Schultz high-low spread estimator as presented by Corwin and Schultz (2012). In order to increase robustness in the models, we apply both liquidity measures. We are limited to the abovementioned liquidity proxies as other liquidity proxies such as the Range measure (Han and Zhou, 2008) and the Amihud measure (Amihud, 2002) requires intraday trading volumes, which are not available for green bonds through sources such as the TRACE database. Additionally, we are unable to implement the LOT liquidity estimator as presented by Chen et al. (2007) and Wulandari et al. (2018) as it is suitable for corporate bonds, whereas this study sample includes a more diverse set of bonds.

4.8.1 Bid-Ask Spread

The most employed measure to derive liquidity risk of financial instruments is the bid-ask spread (E.g., Chen et al. 2007; Beber, Brandt and Kavajecz, 2008; Wulandari et al. 2018; Zerbib, 2019). For each quarter, the spread for each bond is calculated by subtracting the bid from the ask quote, divided by the average bid and ask price, in accordance with Chen et al. (2007). The bond-year's proportional bid-ask spread is then calculated as the mean of the quarterly proportional spreads. To maximise our sample size, we calculate the annual proportional spread if there is a minimum of one quarterly bid-ask quote for the year. The historical bond price data is collected from Thomson Reuters Eikon. The bid-ask spread is calculated as follows:

$$LIQ_{BA} = BA_{i,t} = \frac{Ask_{i,t} - Bid_{i,t}}{\frac{Ask_{i,t} + Bid_{i.t}}{2}} \tag{11}$$

where

$BA_{i,t}$	is the bid-ask spread of bond i in time t
$Ask_{i,t}$	is the ask price of bond i in time t
$Bid_{i,t}$	is the bid price of bond i in time t

Although being the most utilised liquidity measure in academic research it comes with several drawbacks. The bid-ask spread is not always available for all bonds or for all time periods. This can be seen for thinly traded bonds or more mature bonds (Chen et al. 2007). As a result, we apply our second liquidity estimator, Corwin Schultz high-low spread estimator. It is important to note that the estimator measures liquidity and its associated costs differently than the bid-ask spread. The Corwin Schultz high-low spread estimator measures information asymmetry costs arising due to traders having more information over market makers and other participants making the market inefficient. Due to the presence of asymmetric information, markets makers and other participants require more compensation for trading with informed trades which in turn leads to higher spreads (Corwin and Schultz, 2012). Compared to the bid-ask spread that reflects cumulative demand and supply for the bond (or lack of) which imposes a liquidity cost for market participants and thereby neglects certain aspects to explain liquidity such as asymmetric information.

4.8.2 Corwin Schultz High-Low Spread Estimator

The Corwin Schultz high-low spread estimator is based on two main estimates that reflect both the true variance of the security price and the bid-ask spread. This allows the estimator to solve for both the spread and the variance by deriving two equations, a function of the high-low ratio from a single two-day period and a function of the high-low ratios on two consecutive days.

In order to calculate Corwin Schultz high-low spread estimator, we start by calculating the natural logarithm of the highest price over two days and the lowest price over two days:

$$\gamma = \left[ln \left(\frac{H^0_{t,t+1}}{L^0_{t,t+1}} \right) \right]^2 \tag{12}$$

where

$H_{t,t+1}$	is the high price of a bond in day t and $t+1$
$L_{t,t+1}$	is the low price of a bond in day t and $t+1$
γ	is the natural logarithm of the squared quotient of two-day high-low values

We then compute the daily high and low-price adjustments to be able to calculate the difference between the adjustments of a single day and a two-day interval:

$$\beta = \sum_{j=0}^{1} (\ln(\tfrac{H_{t+i}}{L_{t+i}}))^2 \tag{13}$$

where

β	is the daily high and low-price adjustments
H_{t+i}	is the high price of bond i in day t
L_{t+i}	is the low price of bond i in day t

$$\alpha = \frac{\sqrt{2\beta} - \sqrt{\beta}}{3 - 2\sqrt{2}} - \sqrt{\frac{\gamma}{3 - 2\sqrt{2}}} \tag{14}$$

where

α	is the difference between the adjustments of a single day and two-day intervals

The effective spread proxy is then computed using the following formula:

$$LIQ_{cs} = Spread = \frac{2 * (e^{\alpha} - 1)}{1 + e^{\alpha}} \tag{15}$$

Similar to other liquidity estimators, the Corwin-Schultz high-low spread estimator is not defined when the computation yields a value less than zero since a spread de facto cannot be negative. Hence, we return a zero value when and if the estimator returns a value below zero (Corwin and Schultz, 2012). Furthermore, we use the same methodology as Corwin and Schultz (2012) to proxy the true high and low prices that are not observed for infrequently traded bonds by using the latest high and low price available from Thomson Reuters Eikon.

4.9 Duration and Modified Duration

Due to the cash flow schedules of bonds, the time to maturity does not reflect the true period over which the bond's total return is earned. Thus, to properly compare the characteristics between bonds with, for example, similar maturity structures, time to maturity is insufficient.

Duration (also known as Macaulay's duration) measures the speed of payment of a bond, hence its price risk relative to other bonds of the same maturity by measuring the average maturity of the bond's cash flow stream. Duration is the weighted average time until the bondholder receives cash flows from a bond, where the weights are the present values of the cash flows, measured in years. (Choudhry 2004, p.29) Duration is given by the formula below:

$$D = \frac{\sum_{n=1}^{N} \frac{nC_n}{(1+r)^n}}{P} \tag{16}$$

where

- P is the bond clean price (excluding any accrued interest)
- C is the bond cash flow at time n
- r is the current yield
- n is the number of interest periods
- D is the duration of the bond (also known as Macaulay duration)

The Macaulay duration is measured in years, which carries low informational value and practical use. Therefore, we transform the measurement into modified duration, one of the most commonly used risk and hedge calculation measures used in the markets (Choudhry 2004, p.31). Modified duration is given by the following formula:

$$MD = \frac{D}{(1+r)} \tag{17}$$

where

- D is the duration of the bond (also known as Macaulay duration)
- r is the current yield
- MD is the modified duration of the bond

Modified duration measures the average cash-weighted term to maturity of a bond and is important to consider as bonds with higher durations, ceteris paribus, have greater price volatility, i.e. interest rate sensitivity. It is therefore an appropriate measure to include when analysing yield spreads as it captures the effect of the bond's term to maturity and interest rate sensitivity. Therefore, in accordance with Sarkar and Hong (2004) and Wulandari et al. (2018), yearly modified duration is included as a control variable in our estimations.

4.10 Additional Control Variables

The empirical analysis control for other variables that may affect the yield spreads for both green and conventional bonds. The variables are chosen based on previous studies to increase the explanatory degree and robustness of the models. Besides the previously presented variables, we include controls for credit rating, sector, year, currency, maturity, the amount issued, ECB asset purchase program eligibility and institutional issuers in our models.

A majority of the labelled green bonds have not received a credit rating, thus constituting the primary restrictive selection criteria. Most rated bonds have a credit rating from S&P while the remainder of them have ratings from either Moody's or Fitch, or both. To harmonise the credit rating variable, we convert all ratings to a corresponding rating from S&P in accordance with Jewell and Livingston (1999) and create a dummy variable for *Rating*. We also construct a *Sector* dummy variable to control for sector fixed effects. Bloomberg Level 3 Industry Classifications are collected for all bonds and is modified according to the green bond classifications used by SEB: *Supranationals, Government Agencies, Financials, Corporate Utilities, Corporate Others* and *Corporate REITs* (See Table 11 in appendix). Furthermore, we construct a dummy variable for ECB asset purchase program eligibility collected from Thomson Reuters Eikon, where a bond that is eligible for the programme is represented by a 1 and 0 otherwise. Additionally, we interact the *Green* with *Year* as a dummy variable to capture the green bond yield spread premium for the five years we are studying. We exclude *Coupon* from the regression models due to three main reasons. Firstly, we only study fixed coupon bonds, which yields intertemporal stability in the variable, reducing its explanatory effect. Secondly, since yield spreads are primarily constituted by the coupon, it would lead introduce endogeneity in the specifications. Finally, it is not utilised by Zerbib (2019). We include coupon information in our summary statistics as it contains informational value for issuer and investors. A complete list and descriptions of the variables included in this study are featured in Section 4.10.1 below.

4.10.1 Variable Summary

Variables	Descriptions	Source
Amount	Amount issued	(a)
Amount_USD	Amount issued in U.S. Dollar (FX-rate as of issue date)	(a)
LIQ_{BA}	The ask price (*Pask)* minus the bid price (*Pbid)* divided by the average (spread) of both prices	(b)
LIQ_{CS}	Corwin Schultz High-Low Spread Estimator (median of daily spreads used as standard)	(b)
LIQ_{CS}_75th	Corwin Schultz High-Low Spread Estimator (75th percentile of daily spreads)	(b)
LIQ_{CS}_95th	Corwin Schultz High-Low Spread Estimator (95th percentile of daily spreads)	(b)
LIQ_{CS} _Vol	Rolling twelve-month volatility of Corwin Schultz High-Low Spread Estimator	(b)
Country	Country of risk (domicile)	(a)
Coupon	Coupon rate	(a)
Currency	Issued currency	(a)
$MD_{i,t}$	Modified duration of bond *i* in year *t*	(b)
ECB	Dummy variable equal to 1 if bond is eligible for ECB bond buy-back programme and 0 otherwise	(b)
Green	Dummy variable equal to 1 if bond is labelled as green and 0 otherwise (if conventional bond)	(a)
Green x Year	Dummy variable interacting the *Green* variable with the *Year* variable (2014-2018)	(a)
Institutional	Dummy variable equal to 1 if bond is issued by municipalities, government agencies or supranational institutions such as the European Investment Bank and 0 if private sector issuer	(a)
Issue_Date	Issue date of the bond	(a)
Issue_Year	Issue year of the bond	(a)
Maturity	Time to maturity (remaining life of bonds)	(b)
P_{ask}	Clean bond ask price	(b)
P_{bid}	Clean bond bid price	(b)
Rating	Issuer or latest available bond rating (converted to S&P rating scale)	(a)
$R_{i,t}$	Daily return of bond *i* in year *t*	(b)
Sector	Bloomberg level three industry classification with some adjustment according to SEB classification to avoid overly dominant groups (six sectors in final sample)	(a)
Year	Year dummy for each year of study period (2014-2018)	
YS	Yield spread, the difference between bond yield and the relevant government bond yield	(b)

(a) The Bloomberg Terminal; (b) Thomson Reuters Eikon. *(Time period of interest: 2013-12-31 to 2018-12-31)*

4.11 Panel Regression

As is common within the field of social sciences, the most accurate methodological approach for testing our research question is unavailable given that we cannot access the counterfactual information (i.e. what outcomes would we observe if the same bond would not have been "green"?). The second-best alternative, a completely randomized trial, is also not viable as it would require that green and conventional bonds are issued post-trial with the addition of several ad-hoc procedures to satisfy randomness. Since we only have access to data on already issued bonds, we are left with the third best alternative, implementing econometric specifications to compare the characteristics of green bonds to their closest conventional neighbour. Thus, we adopt a panel regression to analyse the yield spreads of a green bond sample compared to a similar conventional bond sample.

Panel analysis have gained a solid footing in financial literature and have been especially pertinent as it relates to comparing socially responsible versus conventional investment funds, measuring bond credit risk and the effect of volatility on returns (Gregory, Matatko and Luther, 1997; Kreander et al. 2005; Renneboog, Ter Horst and Zhang, 2008). Pairs of matched bonds have also been used to control for credit risk as well as for evaluating liquidity premia (Crabbe and Turner, 1995; Helwege and Turner, 1999; Dick-Nielsen, Feldhütter and Lando 2012; Helwege et al. 2014). Based on these considerations, the rationale for the application of a panel data method when studying green bonds becomes clear. Both Zerbib's (2019) study of yield premiums and Wulandari et al. (2018) study of liquidity premia base their studies of green bonds on a matching method presented by Helwege et al. (2014).

We adopt two panel data methods to investigate the yield spread difference between green bonds and conventional bonds to determine if there is a negative premium. We use a pooled ordinary least square (OLS) regression and a fixed-effects estimation (FE) in accordance with Chen et al. (2007) and Baker et al. (2018). This type of research setting tends to yield intertemporal stability in the independent and control variables. This means that the variables representing the bond characteristics have a low degree of variation year to year within each bond, such as currencies and credit ratings. We use a cluster-robust method on the bonds in our main regressions to address serial correlation in the model variables and the residuals. The method controls for dependence across observations over quarters and presents standard errors correcting for heteroskedasticity. While pooled OLS rely on weaker assumptions because it allows for the residuals to be dependent within a cross-sectional unit, we include OLS specifications as it will add robustness to our estimations paired with an FE estimation due to the intertemporal stability of the variables. Additionally, the pooled OLS does not consider the differences between idiosyncratic issuer effects, which likely has a significant effect on bond yield spreads. The FE model is used to compare bonds with themselves across the sample period as it generates a within issuer estimator, as opposed to the OLS that compares bonds with others in the sample. Our model specifications for the regressions to determine the effects on the green bond premium are listed below and the variable specifications are provided above.

$$Model\ 1{:}\ Yield\ Spread_{i,t} = \beta_0 + \beta_1 Green_i + \beta_2 \log(Amount_{USD})_i + \beta_3 \log(MD)_{i,t} + \beta_4 LIQ_{BA_{i,t}} + \beta_5 LIQ_{CS_{i,t}} + \beta_6 Rating_{i,t} + \beta_7 Sector_i + \beta_8 Currency_i + \beta_9 Year_t + \mu_{i,t}$$

$$Model\ 2{:}\ Yield\ Spread_{i,t} = \beta_0 + \beta_1 Green_i + \beta_2 \log(Amount_{USD})_i + \beta_3 \log(MD)_{i,t} + \beta_4 LIQ_{BA_{i,t}} + \beta_5 LIQ_{CS_{i,t}} + \beta_6 Rating_{i,t} + \beta_7 Sector_i + \beta_8 Currency_i + \beta_9 Year_t + \alpha_i + \mu_{i,t}$$

$$Model\ 3{:}\ Yield\ Spread_{i,t} = \beta_0 + \beta_1 Green_i + \beta_2 \log(Amount_{USD})_i + \beta_3 \log(MD)_{i,t} + \beta_4 LIQ_{BA_{i,t}} + \beta_5 LIQ_{CS_{i,t}} + \beta_6 Institutional_i + \beta_7 ECB_i + \beta_8 Rating_{i,t} + \beta_9 Sector_i + \beta_{10} Currency_i + \beta_{11} Year_t + \mu_{i,t}$$

$$Model\ 4{:}\ Yield\ Spread_{i,t} = \beta_0 + \beta_1 Green_i + \beta_2 \log(Amount_{USD})_i + \beta_3 \log(MD)_{i,t} + \beta_4 LIQ_{BA_{i,t}} + \beta_5 LIQ_{CS_{i,t}} + \beta_6 Institutional_i + \beta_7 ECB_i + \beta_8 Rating_{i,t} + \beta_9 Sector_i + \beta_{10} Currency_i + \beta_{11} Year_t + \alpha_i + \mu_{i,t}$$

$$Model\ 5{:}\ Yield\ Spread_{i,t} = \beta_0 + \beta_1 Green_i\ x\ Year_t + \beta_2 \log(Amount_{USD})_i + \beta_3 \log(MD)_{i,t} + \beta_4 LIQ_{BA_{i,t}} + \beta_5 LIQ_{CS_{i,t}} + \beta_6 Institutional_i + \beta_7 ECB_i + \beta_8 Rating_{i,t} + \beta_9 Sector_i + \beta_{10} Currency_i + \alpha_i + \mu_{i,t}$$

We specify five models to control for fixed and time-varying factors and to study if there are a negative green bond premium in order to test the hypothesis presented earlier in the paper. Model 1 consists of the variables presented above where we run a pooled OLS estimation with issuer cluster-robust standard errors to deal with heterogeneity. Model 2 consists of the same variables as in model 1 but we run a fixed effect estimation with issuer cluster-robust standard errors rather than a pooled OLS. We refer to these two models as our base models. In Model 3 and 4 we add the control variables *ECB* and *Institutional* to reduce potential omitted variable bias while aiming to increase the proportion of variance explained by our models. In Model 3 we run a pooled OLS issuer cluster-robust standard errors estimation and in Model 4 we run a fixed effects issuer cluster-robust standard errors regression similar to Model 1 and 2. Model 5 consists of the same variables and specification as in Model 4 but we have omitted the variable *Green* and replaced it with a green year effect for each year during the study period using the interaction dummy variable *Green x Year*.

4.12 Further Statistical Tests and Variable Transformation

4.12.1 Breusch Pagan Test

We conduct Breusch Pagan test for heteroskedasticity, i.e. that we do not have a constant variance between the variables and the error term. The presence of heteroskedasticity would introduce a bias to our estimators, indicating that we should refrain from interpreting the OLS results. However, should heteroskedasticity be present, we proceed with the OLS models using heteroskedasticity-robust inference after the OLS estimation.

4.12.2 Winsorising

To deal with outliers in our dataset, we have chosen to winsorise the variables LIQ_{BA} and LIQ_{CS} on the 1st and 99th percentile to increase the robustness of statistical inferences and improve our statistical efficiency through the removal of the effect spurious outliers may cause.

4.12.3 Normality

Regression models of financial data are rarely normally distributed which the models assume that the residuals are. Therefore, we test all the variables for kurtosis and skewness, in case a variable residual shows a skewness of -0,5 to 0,5 or kurtosis between -1 and 1 it is deemed to be normally distributed which the model assumes. To ensure that estimations comply with the assumption of normality, we have chosen to use the natural logarithm of the variables that show a diverged result in terms of skewness and kurtosis (Stock and Watson, 2011).

4.12.4 Multicollinearity

Since our Pearson correlation matrix indicates several intercorrelations between the variables in our study, there is a risk that our specifications suffer from multicollinearity, i.e. that the variables in our regression models can be linearly predicted by the other variables. To control for this, we run a variance inflation factor ("VIF") tests on our models.

5. Empirical Results

5.1 Descriptive Statistics

Table 1 presents the Pearson's correlation coefficients of the variables used in the analysis of a pooled sample of green and conventional bonds. We find that all the key control variables have a statistically significant correlation with the dependent variable yield spread, with the expected economic impacts. Generally, correlations are low to moderate, not exceeding -0.80 to +0.80, which could indicate risks for multicollinearity issues. When examining the strongest negative correlators with yield spread in order of magnitude, we find that higher credit ratings, institutional issuers, issue size and, ECB asset purchase program eligibility all impacts yield spreads negatively. Overall, this indicates that less risky bonds are rewarded with lower yield spreads. Notably, there is also a significant negative correlation between green bonds and yield spreads. However, when examining the correlations of the Green variable, we cannot draw the same conclusions regarding their inherent riskiness. We cannot establish a statistically significant indication that green bonds tend to have superior liquidity spreads, credit ratings or institutional issuers, indicating that the lower coupons found and yield spreads for the green bonds is likely to be propelled by other factors and preferences, ECB eligibility seems to be one such variable. When examining the strongest positive correlators with yield spread in order of magnitude, we find that higher coupons, longer durations and higher liquidity spreads all lead to higher yield spreads.

As provided in the summary statistics, see Table 2, we find similar characteristics between the variables of the study when comparing green with conventional bonds, with the most notable difference seen in the larger issuance size with the conventional bonds (for more detail, see Table 6 in the appendix). Both the amount issued, and modified duration suffer from skewness in their residuals, which is why we use the natural logarithm of the variables. Since we construct our sample based on issuers, the variable Institutional is similar between the bond types, with a slight majority of issuers being institutional. The dummy variable representing ECB asset purchase programme eligibility is a bond-specific rather than issuer specific variable, which explains the differences between the bond types (32.6% of conventional bonds and 27.3% of green bonds). Univariate regression analysis of the differences in means indicate that there is a difference in LIQ_{CS} between green bonds and conventional bonds (p-value 0.05).

Table 1. Correlation Matrix

	YS	Green	Amount_USD	LIQ_{BA}	LIQ_{CS}	MD	ECB	Coupon	Institutional	Rating
YS	1									
Green	-0.088**	1								
Amount_USD	-0.165***	-0.108***	1							
LIQ_{BA}	0.031**	-0.011	-0.011	1						
LIQ_{CS}	0.063***	-0.023	-0.002	0.110***	1					
MD	0.108***	-0.063***	-0.008	-0.032**	0.198***	1				
ECB	-0.042***	-0.044***	0.076***	-0.015	0.027**	0.106***	1			
Coupon	0.274***	-0.104***	-0.048***	0.053***	0.037***	0.052***	-0.072***	1		
Institutional	-0.402***	0.017	0.183***	-0.004	-0.062***	-0.058***	-0.058***	-0.074***	1	
Rating	-0.609***	-0.010	0.109***	-0.011	-0.018	-0.005	-0.022	-0.201***	0.513***	1

Note: Lower-triangular cells report Pearson's correlation coefficients. The variables included in the table are **(1) YS** (Yield spread, the difference between bond yield and the relevant government bond yield) **(2) Green** (Dummy variable equal to 1 if bond is labelled as green and 0 otherwise (if conventional bond)) **(3) Amount_USD** (Amount issued in U.S. Dollar (FX-rate as of issue date)) **(4) LIQ_{BA}** (The ask price (Pask) minus the bid price (Pbid) divided by the average (spread) of both prices) **(5) LIQ_{CS}** (Corwin Schultz High-Low Spread Estimator (median of daily spreads used as standard)) **(6) MD** (Modified duration) **(7) ECB** (Dummy variable equal to 1 if bond is eligible for ECB bond buy-back programme and 0 otherwise) **(8) Coupon** (Coupon rate) **(9) Institutional** (Dummy variable equal to 1 if bond is issued by municipalities, government agencies or supranational institutions such as the European Investment Bank and 0 if private sector issuer) **(10) Rating** (Issuer or latest available bond rating (converted to S&P rating scale). The Rating variable is constructed according to the S&P long-term rating scale in ascending order, i.e. the lowest sample bond rating (B+) is denominated as 1 and the highest sample bond rating (AAA) is denominated as 16. */**/*** indicates statistical significance at the 10/5/1 percent level.

Table 2. Summary Statistics

	Green						*Conventional*						*Diff*	
Variable	**n**	**Mean**	**Median**	**Min**	**Max**	**SD**	**n**	**Mean**	**Median**	**Min**	**Max**	**SD**	**Mean**	**P-Value**
YS (bps)	978	79.086	67.599	-360.78	832.7	75.368	4,217	82.297	74.047	-285.275	711.08	66.53	-3.21	(0.074)
Amount_USD (m)	978	611.7	500	1	17.849.1	949.5	4,217	1,234.5	575	1	51.395.1	2.436.6	-622.80	(<0.001)
LIQ_{BA}[2] (bps)	978	0.013	0.002	0	0.503	0.071	4,217	0.017	0.002	0	0.503	0.081	-0.004	(0.205)
LIQ_{CS}[2] (bps)	978	0.002	0.002	0	0.007	0.001	4,217	0.002	0.002	0	0.007	0.001	0.001	(0.050)
MD (%)	978	5.638	4.629	0.258	25.935	3.998	4,217	6.341	5.395	0.359	26.541	4.471	-0.70	(<0.001)
ECB[1]	978	0.273	0	0	1	0.446	4,217	0.326	0	0	1	0.469	-0.05	(0.001)
Coupon (%)	978	2.2	1.9	0	11.7	1.8	4,217	2.6	2.5	0	16	1.7	-0.40	(<0.001)
Institutional[1]	978	0.569	1	0	1	0.496	4,217	0.547	1	0	1	0.498	0.02	(0.225)

Note: The variables included in the table are **(1) YS (bps)** (Yield spread, the difference between bond yield and the relevant government bond yield) **(2) Amount_USD (m)** (Amount issued in U.S. Dollar (FX-rate as of issue date)) **(3) LIQ_{BA} (bps)** (The ask price (Pask) minus the bid price (Pbid) divided by the average (spread) of both prices) **(4) LIQ_{CS} (bps)** (Corwin Schultz High-Low Spread Estimator (median of daily spreads used as standard)) **(5) MD (%)** (Modified duration) **(6) ECB** (Dummy variable equal to 1 if bond is eligible for ECB bond buy-back programme and 0 otherwise) **(7) Coupon (%)** (Coupon rate) **(8) Institutional** (Dummy variable equal to 1 if bond is issued by municipalities, government agencies or supranational institutions such as the European Investment Bank and 0 if private sector issuer). There are 172 unique issuers, 1,795 unique bonds (of which 397 green 1,398 conventional bonds) and 5,195 bond year observations from the study period 2014 to 2018. Sample includes labelled green and conventional bonds issued between 2010 and 2018. P-values test for differences in means are calculated using a one-variable regression model, with standard errors adjusted for issuer-level clustering. Bond pricing, ECB eligibility and duration data collected from Thomson Reuters Eikon. Data for amount issued and coupons collected from The Bloomberg Terminal. See main text for further explanations of variable descriptions, section 4.10.1. [1] Dummy variables [2] Winsorised at 1^{st} and 99^{th} percentile to deal with outliers.

5.2 Regression Results

Table 3. Multivariable Regression Analysis

Dependent variable: Yield Spread VARIABLES	(Model 1) POLS	(Model 2) Issuer Fixed Effects	(Model 3) POLS	(Model 4) Issuer Fixed Effects	(Model 5) Issuer Fixed Effects
Green (dummy)	-3.719**	-4.524***	-3.699**	-4.535***	
	(1.698)	(1.470)	(1.699)	(1.469)	
Amount_USD (log)	-7.104***	-6.637***	-7.104***	-6.666***	-10.576***
	(0.450)	(0.478)	(0.450)	(0.478)	(1.635)
MD (log)	4.193***	4.509***	4.176***	4.587***	1.397**
	(1.098)	(0.949)	(1.098)	(0.949)	(1.474)
LIQ_{BA}	2.386	-6.688	2.372	-7.127	3.139
	(8.305)	(7.311)	(8.306)	(7.309)	(20.900)
LIQ_{CS}	7,416.943***	6,221.986***	7,404.215***	6,250.712***	2,668.714**
	(578.837)	(531.188)	(579.617)	(531.019)	(501.920)
Institutional (dummy)			-21.117***		
			(2.178)		
ECB (dummy)			0.639	-3.841**	-1.931*
			(1.462)	(1.532)	(1.245)
Green x Year 2015					7.011
					(7.308)
Green x Year 2016					-3.152
					(6.858)
Green x Year 2017					-16.737**
					(6.703)
Green x Year 2018					-5.884**
					(5.246)
Constant	451.773***	117.489***	451.764***	118.261***	90.981***
	(20.424)	(12.387)	(20.426)	(12.384)	(25.867)
Observations	5,195	5,195	5,195	5,195	5,195
Adjusted R^2	0.556	0.388	0.556	0.389	0.397
Full fixed effects	No	Yes	No	Yes	Yes
Number of Issuers		172		172	172

Note: This table reports the results of pooled OLS and fixed effects regressions of the yield spread as a function of the green bond label dummy, key bond and issuer characteristics controls in order to measure the green bond yield premium. The dependent variable is denominated in basis points and shows investor return above a 'risk-free' sovereign bond benchmark. The study period covers 2014 to 2018 and includes bonds issued between 2010 and 2018. "Model 1" is the pooled OLS base model. "Model 2" is the fixed effects base model. "Model 3" is the extended pooled OLS model, including controls for institutional issuers and ECB asset purchase program eligibility. "Model 4" is a fixed effects model with otherwise identical specifications as "Model 3". "Model 5" adds interactions with green and years to measure if the green bond premium is stable over time. To preserve space, we do not report the coefficients for the four different issuer fixed effects controls. We include six sector controls (details found in Table 11 in the appendix), five-year dummies, 15 rating controls based on S&P long-term credit ratings and 19 currency control dummies in all models' specifications. Standard errors are clustered at issuer level, shown in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level. The variables included in the table are **(1) YS** (Yield spread, the difference between bond yield and the relevant government bond yield) **(2) Green (dummy)** (Dummy variable equal to 1 if bond is labelled as green and 0 otherwise (if conventional bond)) **(3) Amount_USD (log)** (Amount issued in U.S. Dollar (FX-rate as of issue date)) **(4) MD (log)** (Modified duration) **(5) LIQ_{BA}** (The ask price (Pask) minus the bid price (Pbid) divided by the average (spread) of both prices) **(6) LIQ_{CS}** (Corwin Schultz High-Low Spread Estimator (median of daily spreads used as standard)) **(7) Institutional (dummy)** (Dummy variable equal to 1 if bond is issued by municipalities, government agencies or supranational institutions such as the European Investment Bank and 0 if private sector issuer **(8) ECB (dummy)** (Dummy variable equal to 1 if bond is eligible for ECB bond buy-back programme and 0 otherwise) **(9) Green x Year** (Dummy variable interacting the Green variable with the Year variable (2014-2018)) **(10) Year dummies** Year dummy for each year of study period (2014-2018) **(11) Rating dummies** (Issuer or latest available bond rating (converted to S&P rating scale) **(12) Sector dummies** (Bloomberg level three industry classification with some adjustment according to SEB classification to avoid overly dominant groups (six sectors in final sample)) **(13) Currency dummies** (Issued currency).

5.2.1 Base Models

Our base models (Model 1 and 2) shows statistically significant results for the independent variable *Green* (p-value 0.029) and the control variable LIQ_{CS} (p-value <0.001), but not for LIQ_{BA}. The results indicate that green bonds in our sample on average, ceteris paribus, have a lower yield spread (negative yield premium) than conventional bonds during the study period of 3.72 bps in Model 1 and 4.52 bps in Model 2. The models indicate that on average, ceteris paribus, one σ increase in LIQ_{CS} leads to an increase in yield spread of 14.83 and 12.44 bps for the bonds in our sample in Model 1 and 2 respectively. LIQ_{BA} did not show statistical significance in any of the models (p-values 0.774 and 0.360). Furthermore, we find that *log(Amount_USD)* is statistically significant (p-value <0.001) in both Model 1 and 2. The models show that one percent increase in issued amount on average, ceteris paribus, negatively impacts yield spreads with 0.07 bps respectively during the study period. Finally, we find that the variable *log(MD)* is statistically significant (p-value <0.001) in both Model 1 and 2. This indicates that a one percent increase in modified duration on average, ceteris paribus, increases yield spreads with 0.042 and 0.045 bps respectively during the study period. The models indicate an adjusted R^2 of 0.556 for Model 1 and an adjusted R^2 of 0.388 for Model 2.

5.2.2 Controlling for ECB and Institutional Issuers

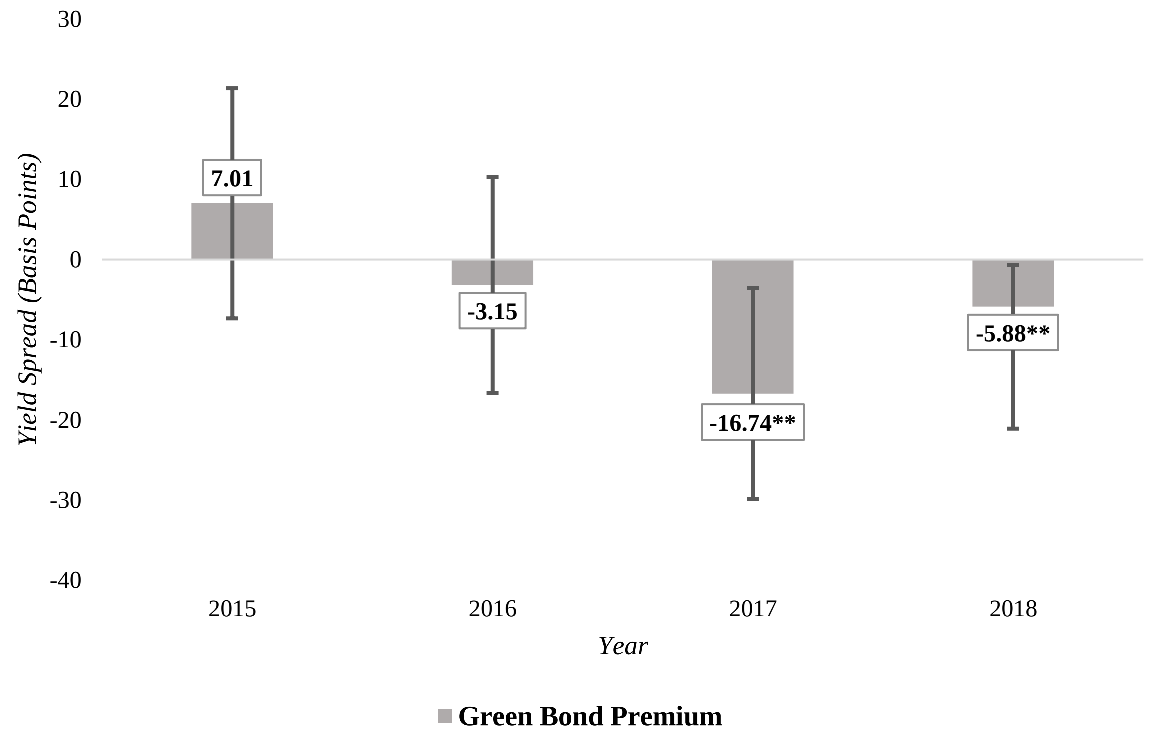
As seen in Table 3, our extended models (Model 3 and 4) show similar results as our base models for the independent and control variables. The models indicate an adjusted R^2 of 0.556 for Model 3 and an adjusted R^2 of 0.389 for Model 4. When controlling for *Institutional* issuers, we find statistical significance (p-value <0.001) in Model 3, while the variable is omitted in Model 4 due to collinearity. Model 3 indicates that bonds issued by institutions on average, ceteris paribus, have 21.18 bps lower yield spreads during the study period. The *ECB* variable is not statistically significant in Model 3 but is statistically significant (p-value 0.012) in Model 4. Model 4 indicates that bonds eligible for the ECB asset purchase programme on average, ceteris paribus, have 3.84 bps lower yield spreads during the study period.

5.2.3 Yearly Green Bond Premia

Our model controlling for yearly differences in green bond yield spread premia (Model 5) show results in line with previous models, however, with lower p-values for LIQ_{CS}, *log(MD)* and *ECB*. Model 5 indicates that on average, ceteris paribus, one σ increase in LIQ_{CS} leads to an increase in yield spread of 5.34 bps for the bonds in our sample during the study period. The *Green x Year* dummy allows us to disentangle the green bond yield premium per year. The observation years 2015 and 2016 does not show statistical significance (p-values of 0.338 and 0.646 respectively), while 2017 and 2018 show statistically significant results (p-values of

0.013 and 0.047 respectively). Model 5 indicates that on average, ceteris paribus, green bonds in our sample had 16.74 and 5.88 bps lower yield spread in 2017 and 2018 than conventional bonds respectively relative to 2014, as seen in Figure 2 below.

Figure 2. Green Bond Premium by Year



Note: Average green bond yield spread premium by year (bps) based on issuer fixed effects Model 5. 95% confidence interval shown by black indicators. */**/*** indicates statistical significance at the 10/5/1 percent level.

5.3 Hypotheses Testing

The quality and consistency of our model specifications (i.e. pooled OLS versus issuer fixed effects) depends on a range of factors. As previously discussed, we believe that the characteristics of our data and our empirical approach makes the fixed effects issuer cluster-robust standard errors models the most appropriate and least biased for conducting hypotheses testing. To reduce risks for omitted variable bias we proceed with Model 4. Our hypothesis concerns the presence of a green bond yield premium on the secondary labelled green bond market based on investor preference and utility.

H1: Green bonds have a negative yield premium compared to conventional bonds

Model 4 indicates a *t*-stat of -3.09 for green labelled bonds in relation to yield spread for our sample. Thus, we reject the null hypothesis that there is no green bond yield premium compared to conventional bonds. This shows support for the revised CAPM presented by Baker et al. (2018), indicating that investors with nonpecuniary preferences find utility from green bonds, subsequently requiring lower returns from such investments:

$$r = \frac{r_m}{\sigma_m^2} \Sigma w_m = \beta r_m - \frac{a_2}{a_1 + a_2} e$$

5.4 Test for Multicollinearity

We could potentially face multicollinearity issues with our variables, where the variables in our multiple regressions can be linearly predicted from other variables. To control for these issues, we run a variance inflation factor (VIF) test on our regressions. The VIF test of all variables shows values in the range of 1.04 and 4.61, indicating a low to moderate degree of multicollinearity (see Table 12 in the appendix).

5.5 Test for Heteroskedasticity

The specified models in our paper could suffer from heteroskedasticity, which implies that we do not have a constant variance between the error terms and the independent and control variables. As a result, we do not have a linear regression and the models are not applicable for the OLS method. We have therefore conducted a Breusch-Pagan test for model 1 and 3 and a Modified Wald test for model 2, 4 and 5 which controls for heterogeneity in our models. As seen in Table 13 in the appendix we reject the null hypothesis for all models which indicates that heteroskedasticity is assumed. We deal with this problem by using issuer cluster-robust standard errors to the models as previously addressed.

5.6 Test for Autocorrelation

To further control for potential biases in our estimations, we conduct tests for autocorrelation using the Breusch-Godfrey test for our pooled OLS models and Wooldridge test for autocorrelation in the fixed effects panel data. As seen in Table 14 in the appendix, we fail to reject the null hypothesis of no first-order autocorrelation on a significant level in all model specifications, thus indicating that they are not suffering from autocorrelation biases.

6. Robustness Tests for Liquidity Biases

Since bond pricing relies on liquidity factors to a great extent, our robustness checks will focus on expanding the liquidity controls in our model specifications to ensure that the green bond yield premium is not only a result of liquidity differences. The robustness checks are based on Model 4 using the same fixed effects cluster-robust standard errors. Additional liquidity variables derived from the Corwin Schultz high-low estimator are added since the high-low estimator is more robust than the bid-ask spread. The study period 2014 to 2018 have generally been characterised by benign economic conditions and strong asset price developments, backed by initiatives such as the ECB asset purchase programme. However, investors analysing asset liquidity will unlikely consider the median or average liquidity spreads to be the most critical factor, as high liquidity spreads (i.e. liquidity in securities are low) tend to coincide with investors need to transact. For example, the bond spread contribution from illiquidity increased dramatically during the subprime crisis 2008, ultimately preventing many investors to sell financial assets (Dick-Nielsen et al. 2012). Even though our study does not cover a period including a financial crisis we still want to estimate the effect of higher percentile liquidity spreads on yield spreads as a form of liquidity stress-tests. Therefore, we construct the variables LIQ_{CS}_75thP and LIQ_{CS}_95thP capturing the 75th and 95th percentile of the Corwin Schultz high-low spread estimator for our sample during the study period. To the best of our knowledge, no other green bond study controls for different liquidity spread percentiles.

Another potential liquidity factor to consider in terms of bond pricing is the historical liquidity of a bond as opposed to the current liquidity, as proxied by bid-ask spreads and Corwin Schultz high-low spread estimator. As our current liquidity proxies only consider daily and quarterly liquidity spreads, there is a potential risk that they only capture the actual costs of liquidity rather than the expected liquidity costs. Dastidar and Phelps (2011) argue that the expected liquidity costs are captured via the historical volatility of liquidity spreads as investors demand additional yield as compensation for the increased risks associated with fluctuating liquidity. Other studies of bond yield spreads, such as Zerbib (2019), use volatility measures to test the robustness of their estimations. Therefore, we introduce a variable capturing historical liquidity spread volatility, $LIQ_{CS}\_Volatility$ calculated as the twelve-month rolling volatility (σ) of the Corwin Schultz high-low spread estimator.

Table 4. Robustness Tests

Dependent variable: Yield Spread	(Model 6)	(Model 7)	(Model 8)
VARIABLES	Issuer Fixed Effects	Issuer Fixed Effects	Issuer Fixed Effects
Green (dummy)	-4.491***	-4.568***	-4.524***
	(1.490)	(1.484)	(1.470)
Amount_USD (log)	-6.552***	-6.520***	-6.637***
	(0.485)	(0.483)	(0.478)
MD (log)	7.986***	7.168***	4.509***
	(0.914)	(0.918)	(0.949)
LIQ_{BA}	-6.304	-10.029	-6.688
	(7.435)	(7.421)	(7.311)
LIQ_{CS}_75thP	165.602*		
	(88.505)		
LIQ_{CS}_95thP		401.909***	
		(62.561)	
LIQ_{CS}			6,222.241***
			(531.289)
LIQ_{CS}_Volatility	10.427	2.009	3.457
	(95.436)	(95.073)	(94.143)
Number of issuers	172	172	172
Adjusted R^2	0.402	0.413	0.378
Full fixed effects	YES	YES	YES

Note: This table reports the results of fixed effects regressions of the yield spread as a function of the green bond label dummy, key bond and issuer characteristics controls to perform additional robustness checks of the negative green bond yield premium. The regression results are to be seen as 'liquidity stress-tests'. The dependent variable is denominated in basis points and shows investor return above a 'risk-free' sovereign bond benchmark. The study period covers 2014 to 2018 and includes bonds issued between 2010 and 2018. "Model 6" includes values of the Corwin-Schultz high-low spread estimator at 75th percentile levels as well as the 12-month rolling volatility of the measure. "Model 7" instead controls for the 95th percentile spread levels. "Model 8" includes median values paired with the 12-month rolling volatility. To preserve space, we do not report the coefficients for the four different fixed effects controls. We include six sector controls (details found in Table 11 in the appendix), five-year dummies, 15 rating controls based on S&P long-term credit ratings and 19 currency control dummies in all model specifications. Standard errors are clustered at issuer level, shown in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level. The variables included in the table are **(1) YS** (Yield spread, the difference between bond yield and the relevant government bond yield) **(2) Green (dummy)** (Dummy variable equal to 1 if bond is labelled as green and 0 otherwise (if conventional bond)) **(3) Amount_USD (log)** (Amount issued in U.S. Dollar (FX-rate as of issue date)) **(4) MD (log)** (Modified duration) **(5) LIQ_{BA}** (The ask price (Pask) minus the bid price (Pbid) divided by the average (spread) of both prices) **(6) LIQ_{CS}_75thP** (Corwin Schultz High-Low Spread Estimator (75th percentile of daily spreads)) **(7) LIQ_{CS}_95thP** (Corwin Schultz High-Low Spread Estimator (95th percentile of daily spreads)) **(8) LIQ_{CS}** (Corwin Schultz High-Low Spread Estimator (median of daily spreads used as standard)) **(9) LIQ_{CS}_Volatility** (Rolling twelve-month volatility of Corwin Schultz High-Low Spread Estimator **(10) Year dummies** Year dummy for each year of study period (2014-2018) **(11) Rating dummies** (Issuer or latest available bond rating (converted to S&P rating scale) **(12) Sector dummies** (Bloomberg level three industry classification with some adjustment according to SEB classification to avoid overly dominant groups (six sectors in final sample)) **(13) Currency dummies** (Issued currency).

When analysing the results of our robustness checks, we conclude that the average negative green bond yield premium of approximately -4 to -5 bps holds when controlling for higher percentile liquidity spreads and historical liquidity volatility. The models indicate an adjusted R^2 of 0.402 for Model 6, 0.413 for Model 7 and 0.378 for Model 8. Overall, the robustness checks indicate similar results for all key independent and control variables compared to our main models, further strengthening the robustness of our findings. Model 6 indicate with statistical significance (p-value 0.061) that when LIQ_{CS} are at 75^{th} percentile levels, a one percent change in spreads on average, ceteris paribus, increases yield spreads by 165.6 bps. Model 7 shows even stronger results for the 95^{th} percentile (p-value <0.001) with a ceteris paribus magnitude of a yield spread increase of 401.91 bps. The results are in line with our expectations, that an increase in liquidity spreads would lead to higher yields as investors demand compensation for lower liquidity, ceteris paribus.

However, we must be careful when interpreting and extrapolating the economic significance of these findings since we are unlikely to experience prolonged periods of abnormally high spreads for the whole market. In the advent of severe market turbulence, spreads are primarily determined by idiosyncratic factors such as ownership concentration and currencies. All robustness models indicate that an increase in Corwin Schultz spread volatility increases yield spreads, however, none of the results are statistically significant (p-values >0.90). These findings contradict the argumentation put forth by Dastidar and Phelps (2011). A plausible explanation could be that since the study period 2014 to 2018 does not contain considerable market turbulence, i.e. historically low volatility in general, bond markets might not have found the spread volatility a key pricing determinant. We cannot rule out that this could change, should market volatility levels accelerate going forward.

7. Analysis and Discussion

7.1 Green Bond Premium Confirmed

All our model specifications confirm that there exists a small average green bond premium of approximately -4 to -5 bps as compared to conventional bonds between 2014 and 2018. The results are intact, even after rigorous robustness checks for liquidity. This is consistent with stakeholder theory as well as previous literature indicating a negative relationship between sustainability and funding costs due to lower overall risk levels (Sun and Cui, 2014; Jiraporn et al. 2014; Oikonomou et al. 2014; Ghouma et al. 2018). Our findings are also in line with previous green bond literature, such as Zerbib's (2019) findings on the secondary green bond market and Baker et al. (2018) study of the primary market for U.S. municipal green bonds. The green premium is smaller than the -7.8 bps found by Karpf and Mandel (2018) in the U.S. municipal green bond market, however, this could be explained by their homogenous sample which is less impacted by factors such as country of domicile or sectors. Furthermore, in line with the findings by Zerbib (2019), we show that the green bond premium is not stable over time, as seen in Figure 2 above. We find that the green bond premia shifted from positive 7.01 bps (p-value 0.338) in 2015 to negative 5.88 bps (p-value 0.047) in 2018, indicating a market evolution increasingly rewarding green labelled bonds. Green bonds have evolved from a novel and niche corner of the fixed-income universe into a widely accepted asset-class. These developments have been propelled by regulatory improvements and a fast-growing investable asset base. Our results indicate that investor confidence and subsequent willingness to pay a premium for sustainability have increased as the green bond product has matured. Even after controlling for institutional issuance and ECB asset purchase programme eligibility, the negative green premium persists.

As previously discussed, a key concept of asset pricing relates to systematic versus idiosyncratic risks, and investors' demand for idiosyncratic risk compensation. There is a clear need to understand whether "greenness" reduces perceived idiosyncratic risks, if merely investor preference towards sustainability is reducing their financial returns in favour of utilities stemming from catering to the popularity of ESG-investments, or both. There are several potential factors that could explain the green bond premium as it relates to idiosyncratic risk. On the one hand, up until today, the green bond market has been dominated by supranational organisations, government agencies, and well-established financial institutions primarily issuing bonds from developed economies with stable currencies and high credit ratings. Such characteristics indicate a comparatively low degree and volatility of idiosyncratic risk associated with the issued bonds. Hence, it could be argued that it is unlikely that the “greenness” of the issued bonds will lower the idiosyncratic riskiness of the investment, and that the green pricing premium results from investors finding inherent utility in ESG. This line of reasoning would call the traditional CAPM into question, as financial returns not being the only factor determining risk appetite for certain type of investors. This would substantiate the modified CAPM-model presented by Baker et al. (2018), which argues that ESG-profiled investors find utility in nonpecuniary compensation.

On the other hand, previous studies have found that CSP and sustainable initiatives lower idiosyncratic riskiness (Sun and Cui, 2014; Jiraporn et al. 2014; Oikonomou et al. 2014; Ghouma et al. 2018). If this is categorically accurate, green bonds with proceeds earmarked for sustainable projects are likely to carry lower idiosyncratic risk than its conventional counterpart, providing a fundamental risk-return motivation for a negative green yield premium in line with the traditional CAPM. Both lines of reasoning are feasible from a theoretical and practical standpoint for explaining the green bond premium, however, our study is unable to discern which pricing dynamic supersedes the other. Furthermore, it might be useful to consider the concept of actual riskiness and perceived riskiness as it relates to idiosyncratic risks. Should the consensus market view have established that green bonds, ceteris paribus, are less risky than conventional bonds, yield spreads will be suppressed. Given the limited historical data, market size and scope of the green bond market, with few if any known defaults (Baker et al. 2018), it seems unfeasible that the market prices risk as efficiently as conventional bonds. Therefore, we cannot rule out the possibility that there could be a discrepancy between perceived riskiness and actual risk, which biases asset pricing.

Besides these theoretical explanations, another important factor to consider is supply and demand in the green bond market, see Section 2.1. We cannot rule out that the green premium is a result from mispricing of green bonds compared to conventional bonds, driven by speculation or ESG-mandates needing to be fulfilled being larger than the capacity of the green bond markets. Of course, if the green premium corresponds to the utility found by ESG focused investors, we cannot specify it as a mispricing. However, the concept of nonpecuniary compensation is tacit and difficult to measure, indicating that we must consider this alternative in our analysis.

Nonetheless, our results, as hypothesised by Baker et al. (2018), supports that there seems to be an influential base of investors finding utility in the green label to such an extent that they are willing to lower their expected returns. Even if prospective green bond investors could find it discouraging having to pay a premium for such assets, it is also important to consider the potential positive stakeholder-related effects such as marketing value, attracting new clients and sustainability contributions. Perhaps such stakeholder effects lead to a larger monetary gain than the negative yield premium, ultimately making the nonpecuniary preference for 'greenness' a preference towards financial returns on a *net basis*.

Our results indicate that holding green bonds has been beneficial for fixed-income investors in recent years as market participants on average have been willing to pay a premium for such assets. Since there seems to be no indication that the attractiveness of green bonds will subdue in the coming years, such positive market sentiment is likely to persist. We can also conclude that liquidity risks relating to green bonds do not seem to be an issue.

When examining our informational contributions through an issuer perspective, we provide insights on how green bonds are priced on the secondary markets, but most importantly on how such instruments provides favourable future refinancing terms as investors pay an increasing premium. By extension, it suggests that current investors can absorb an issuance yield that is lower than what is indicated by the conventional curve. From a theoretical perspective, our results indicate that labelling bonds green can be viewed as costly signalling through certification. Despite the certification value of a green label, the net value of issuing green bonds as opposed to conventional bonds is not captured in our findings. Floatation and compliance costs related to issuing green bonds are rarely disclosed and thus not included in our study. Therefore, issuing entities should evaluate the benefits of a negative yield premium found in our study against additional pre- and post-issuance costs associated with green bonds.

7.2 Liquidity Analysis

Even though our findings indicate that the green bond premium is not determined by liquidity factors, we are faced with a range of uncertainties as it pertains to accurately proxying the liquidity of green bonds. Green bonds generally suffer from limited historical liquidity data availability, as discussed further in Section 4.8. However, we must also address the potential sources of 'unmeasurable' liquidity. Firstly, if green bond markets are dominated by long-term investors, measured liquidity on the secondary markets will be suppressed, even if the 'real' liquidity (i.e. possibility to liquidate holdings if needed) of such instruments would be high due to surging market demand. Even though our study does not capture such dynamics, it is not unreasonable to assume that such is the case, as indicated by Baker et al. (2018) where green bonds on average showed higher ownership concentration. Secondly, holders of green bonds might be reluctant to sell such assets due to factors such as ESG investment mandates and could in times of need to sell holdings prioritise selling other asset classes. This would also result in suppressed measured liquidity in green bonds. The prevalence of such market conditions would create preconditions for a low degree of liquidity for prospective green bond buyers, and a high degree of liquidity available for holders of green bonds, by extension calling our liquidity approximations into question as they are based on trading data. Such a ‘holding-liquidity’ paired with favourable supply and demand dynamics would then further increase the attractiveness of holding such assets. To the best of our knowledge, no other green bond study considers ‘unmeasurable liquidity’ in their discussions.

When analysing the summary statistics, we find that green bonds on average have less than 0.001 percent higher Corwin Schultz spreads (p-value 0.050) than conventional bonds. This indicates that the green bonds in our sample have slightly lower trading liquidity than their conventional counterparties. A plausible explanation could be the previously discussed ‘holding-liquidity’ paired with demand outpacing supply, where investors are more inclined to hold green bonds to maturity rather than actively trading them. Another explanation could stem from green bonds still being a niche product with comparatively low investor adoption during the early parts of the study period (according to Wulandari et al. (2018), green bonds constituted only 0.13% of the aggregate bond markets). Less traded markets tend to decrease market efficiency and drive up spreads. In conclusion, asset liquidity tends to shift over time and our sample only indicate a small difference between the asset classes. However, our findings indicate that there in fact is a statistically significant difference in liquidity spreads between green and conventional bonds, something fixed income investors should be aware of as they evaluate the asset class.

7.3 The Impact from the EU Going Forward

Our findings indicate that the ECB asset purchase program on average reduced yield spreads with a rather modest 3.8 bps during the study period. Even though the magnitude is lower than suggested by both Georgiadis and Gräb (2016) and De Santis et al. (2018). We want to highlight that these studies differ in method and scope from our paper and that 27.5% of the green bonds in our sample are ECB eligible. However, our study still points towards the ECB initiative lowering yield spreads for eligible bonds. This finding is especially interesting for green bonds as the ECB initiative has been active for as long as green bonds have been an asset class. In December 2018 the ECB announced that they will end the net purchases under the asset purchase program (ECB, 2018). The announcement raises the question of how this will affect yield spreads in both the green and conventional bond markets. Details regarding the tapering are opaque, and we can only speculate how pricing dynamics will evolve going forward, especially as the phrasing “net purchases” allows for some continued purchasing. Perhaps the impact on green bonds will remain unchanged or even improve while conventional bond spreads rise due to an ECB bias towards buying and holding green bonds to support sustainable investments. Perhaps the green bond market will take a severe blow when one of the largest market participants reduces their supporting function. In conclusion, we cannot rule out that this shift could impact the validity of our findings going forward, being an important factor for investors, issuers, and academics to consider.

If we extend our future perspective outside the ECB asset purchase program, the EU Action Plan will most likely set the tone for the global adoption of green bonds. By aligning interests and creating universal guidelines green bond markets stands to take one of its biggest developing steps since its inception in 2007. Such a framework has the potential of reducing problems relating to greenwashing, information asymmetry and subsequent adverse selection problems. Even though the EU Action Plan is unlikely to mitigate the prevailing supply and demand dynamics, a similar framework enacted during our study period might have yielded greater stability over time in our findings. We speculate that our findings would have shown larger negative green yield premiums due to the improved ability for issuers to reach separating pricing equilibriums.

7.4 Omitted Variable Bias

Since bond yields are determined by a highly diverse set of idiosyncratic factors, we are aware that our models might suffer from various issuance specific omitted variable biases (unobserved heterogeneity), that is variables which could impact yield spreads between green versus conventional bonds from the same issuer. However, since we rely on issuer fixed effects models, we mitigate potential omitted variable biases stemming from certain issuer specific factors. Such an example could be issuer default risk, which is identical regardless if the bond from said issuer is green or conventional, therefore we do not include this variable in our model specifications.

However, there are variables that could cause omitted variable bias to our results. For example, Baker et al. (2018) control for tax status in their study of green municipal bonds in the US, as pricing of US municipal bonds are highly sensitive to tax features. Our estimations do not control for tax status since our sample contains a highly diverse set of global issuers with oftentimes complex and opaque tax statuses. Tax effects are less notable in the secondary markets and hand collecting such data for all issuers and bonds falls outside the scope of this paper, however, we do realise that omitting this variable could be a source of bias in our results in both directions.

Another source of potential omitted variable bias could stem from omitting controls for certain bond characteristics such as provisions, use of proceeds or embedded optionality structures. Such variables could impact the perceived riskiness and overall attractiveness of fixed income instruments, hence potentially impacting pricing. We refrain from including it primarily due to our large sample size not allowing for detailed data collection of individual bonds, paired with the fact that we include a range of control variables such as credit rating and currency to capture the most important yield spread determinants.

Another variable not included in our models is ownership concentration, as for example included in Baker et al. (2018) study. Ownership concentration could for the purpose of our study primarily shed light on bond liquidity, as high ownership concentration likely entails less frequent trading and vice versa. It could also be of interest to interact the variable over time indicating the presence of long-term investors. A high degree of long-term green bond investors could skew the actual as opposed to the proxied liquidity of the instruments as such investors rarely sell their holdings, even if they might have been able to do so. Our study does not include this variable for two reasons, first, we do not have access to the Thomson Reuters eMAXX database to collect ownership information of US securities. Secondly, we do not have access to a database containing ownership information on non-US bonds, which given our large sample size restricts our ability to efficiently and reliably collecting the needed data.

8. Conclusion

The global battle against climate change requires participance from all members of society, and green bonds have emerged as the front-line response presented by the financial markets. In this paper, we analyse the yield spreads in the secondary markets of a sample of green bonds and a sample of comparable conventional bonds using issuer cluster robust regression models for bonds issued between 2014 and 2018. We find an average significant negative green bond premium of approximately -4 to -5 bps. We also find that the green bond premium is not stable over time, indicating that the attractiveness of the asset class increased significantly between 2014 and 2018. We found the average green premium to be -16.74 and -5.88 bps during 2017 and 2018 respectively. Additionally, the green premium remains after further controls for potential differences in liquidity. Our results are subject to a range of potential explanations in terms of supply-demand, investor preferences and risk. As such, we believe that there is a need to revise the traditional CAPM since investors seem to find utility in sustainability, as hypothesised by Baker et al. (2018).

Our findings contain informational value for investors, issuers, regulatory actors and academics. Investors can gain deeper insights into the pricing and liquidity dynamics for green bonds in the secondary market. Issuers will find our results supportive of bringing green bonds to the market at attractive conditions, combined with promising refinancing terms as opposed to conventional bond alternatives. Our findings also indicate that the demand for green bonds outpaces supply, calling for operational and regulatory measures to further incentivise the issuance of green bonds. We further believe that our study is an important piece in the green bond premium puzzle for academia to continue building on. The main limitations of this study stem from the quality of data and restricted access to liquidity information. Green bonds have only been in existence for a comparatively short period of time, while bonds in general tend to suffer from infrequent trading, decreasing the reliability of our study.

The short to medium term prospects for the green bond market will most likely be characterised by the EU Action Plan, which will harmonise green bonds on a global level. Key concerns with the current state of the green bond markets revolve around the lack of a congruent framework, enforcement and subsequent risks for greenwashing and fraud. Another factor to consider in the coming years is the reduced market interventions by the ECB, as they will reduce the repurchases of global bonds, both green and conventional. This will most likely impact yield spreads and liquidity going forward, shifting the environment in which green bonds always has been issued.

Further research related to this topic could be to conduct a comparative study of green bond yield and liquidity pre- and post the EU action plan and ECB tapering to measure the efficacy of the regulatory interventions. Given the growing number of studies focusing on green bond pricing, we suggest that future research could extend our findings to a deeper analysis of the determinants of the green premium. Such research could include a deeper focus on supply-demand dynamics, investor preferences, and CAPM-analysis. We find the CAPM-discussion especially interesting as it relates to idiosyncratic risks and investor preferences, studying whether green bonds are associated with lower riskiness or if the green bond premium is a result of ESG mandates needing to be fulfilled. We would also suggest a more granular mapping of ‘the typical green bond investor’ to gain a deeper understanding of demand and liquidity dynamics. Finally, we also identify the need for a comparative study between primary issuance and developments in the secondary markets to indicate whether firms are ‘successfully’ pricing yields at issuance.

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Appendix

Table 5. Sample Selection Process

Step 1. Selecting Green Bond Sample
Bloomberg Terminal

Criteria	**Number of bonds**
All bonds (active and matured)	2,506,429
Green Instrument Indicator: Yes	2,055
Issue date between 12/31/2009 - 12/31/2018	1,795
Rating at issuance (S&P, Moody's or Fitch)	855
Coupon type: Fixed	712

Outcome: 712 green bonds from 231 unique issuers

Step 2. Selecting Conventional Bond Sample
Bloomberg Terminal

Criteria	**Number of bonds**
All bonds (active and matured)	2,506,429
Issue date between 12/31/2009 - 12/31/2018	1,854,000
Coupon type: Fixed	670,772
Rating at issuance (S&P, Moody's or Fitch)	108,849
Issuer name (list of 231 issuers found in Step 1.)	15,067
Green Instrument Indicator: No	14,361
Currency (List of all currencies found in Step 1.)	14,012

Outcome: 14,012 conventional bonds from 231 unique issuers

Step 3. Matching Green Bonds
Study period 12/31/2013 - 12/31/2018

Minimum 1 and maximum 10 conventional bonds per green bond based on issuer name, rating, currency and maturity date

303 Green Bonds excluded due to not fulfilling abovementioned criteria

Outcome: 409 green bonds and 1,512 conventional bonds from 172 unique issuers

Step 4. Data gathering
Study period 12/31/2013 - 12/31/2018

Daily, quarterly, yearly and time invariant bond data collected via Bloomberg and Thomson Reuters Eikon.

12 green and 114 conventional bonds excluded due to lack of bond price data via Thomson Reuters Eikon

Final outcome: 397 green bonds and 1,398 conventional bonds from 172 unique issuers
As compared to the sample of Zerbib (2019) including 110 bonds

Table 6. Average Issued Amount by Currency and Bond Type *(million USD[1])*

Currency ID	**Green Bonds**	**Conventional Bonds**	**Total Sample**
AUD	377.6	1 115.4	979.3
BRL	23.9	46.7	41.7
CAD	491.1	3 241.0	2 581.0
CHF	276.4	284.6	283.1
CNY	151.5	80.5	116.0
EUR	945.5	1 275.9	1 206.7
GBP	1 091.4	1 726.3	1 590.2
HKD	44.5	50.8	49.5
INR	124.7	232.7	200.9
JPY	117.8	253.2	223.1
MXN	75.6	92.2	88.4
MYR	14.6	18.9	16.8
NOK	113.3	236.8	199.7
NZD	72.0	164.7	141.5
RUB	23.2	86.9	74.2
SEK	228.5	522.5	417.7
TRY	282.5	51.9	90.3
USD	597.9	1 191.3	1 067.0
ZAR	89.9	39.2	49.3
Total Sample Mean	**627.1**	**1 175.7**	**1 054.4**

[1]*FX-rate as of issue date (see Table 15 for currency definitions)*

Table 7. Number of Bonds by Currency

Currency ID	**Green Bonds**	**Conventional Bonds**	**Total**	**% of Total (1.795)**
AUD	19	84	103	5.7%
BRL	2	7	9	0.5%
CAD	18	57	75	4.2%
CHF	5	23	28	1.6%
CNY	1	1	2	0.1%
EUR	144	543	687	38.3%
GBP	6	22	28	1.6%
HKD	8	30	38	2.1%
INR	5	12	17	0.9%
JPY	2	7	9	0.5%
MXN	3	10	13	0.7%
MYR	1	1	2	0.1%
NOK	3	7	10	0.6%
NZD	8	24	32	1.8%
RUB	1	4	5	0.3%
SEK	41	74	115	6.4%
TRY	1	5	6	0.3%
USD	128	483	611	34.0%
ZAR	1	4	5	0.3%
Total	**397**	**1.398**	**1.795**	100%

Table 8. Number of Bonds by Rating[1]

	Green Bonds	Conventional Bonds	Total	% of Total (1.795)
AAA	156	600	756	42.1%
AA+	25	93	118	6.6%
AA	19	77	96	5.3%
AA-	30	119	149	8.3%
A+	21	102	123	6.9%
A	36	118	154	8.6%
A-	41	113	154	8.6%
BBB+	22	51	73	4.1%
BBB	20	50	70	3.9%
B	1	2	3	0.2%
BBB-	15	55	70	3.9%
BB+	8	14	22	1.2%
BB	2	4	6	0.3%
B+	1	0	1	0.1%
B-	0	0	0	0.0%
Total	**397**	**1.398**	**1.795**	100%

[1]*S&P Long-Term Rating Scale, converted to S&P rating scale if rated by Moody's or Fitch*

Table 9. Number of Bonds by Sector

Sector	Green Bonds	Conventional Bonds	Total	% of Total (1.795)
Government Agency[1]	120	460	580	32.3%
Supranational[1]	96	322	418	23.3%
Financials	71	298	369	20.6%
Corporate Utilities	67	165	232	12.9%
Corporate Others	27	96	123	6.9%
Corporate REIT	16	57	73	4.1%
Total	**397**	**1.398**	**1.795**	**100%**

[1] *Generally defined as Institutional issuers in our 'Institutional' variable*

Table 10. Number of Bonds by Country of Domicile

Country ID	*Country Name*	**Green Bonds**	**Conventional Bonds**	**Total**	**% of Total (1.795)**
US[1]	United States	65	240	305	17.0%
DE[1]	Germany	40	153	193	10.8%
FR[1]	France	40	150	190	10.6%
NL[1]	Netherlands	38	122	160	8.9%
LU[1]	Luxembourg	32	108	140	7.8%
SE[1]	Sweden	24	80	104	5.8%
CA[1]	Canada	14	61	75	4.2%
PH	Philippines	14	51	65	3.6%
AU[1]	Australia	13	49	62	3.5%
FI[1]	Finland	15	43	58	3.2%
NO[1]	Norway	10	45	55	3.1%
KR[1]	South Korea	8	36	44	2.5%
HK	Hong Kong	8	33	41	2.3%
GB[1]	Great Britain	9	28	37	2.1%
JP[1]	Japan	7	30	37	2.1%
IT[1]	Italy	6	20	26	1.4%
CI	Ivory Coast	6	17	23	1.3%
ES[1]	Spain	7	14	21	1.2%
CH[1]	Switzerland	4	17	21	1.2%
IN	India	6	15	21	1.2%
BR	Brazil	5	9	14	0.8%
DK[1]	Denmark	3	11	14	0.8%
AT[1]	Austria	2	10	12	0.7%
ID	Indonesia	2	10	12	0.7%
AE	United Arab Emirates	3	8	11	0.6%
CN	China	2	9	11	0.6%
PL[1]	Poland	2	9	11	0.6%
NZ[1]	New Zealand	4	6	10	0.6%
IE[1]	Ireland	1	4	5	0.3%
KY	The Cayman Islands	2	3	5	0.3%
CR	Costa Rica	2	2	4	0.2%
CL	Chile	2	2	4	0.2%
BE[1]	Belgium	1	3	4	0.2%
Total	**33**	**397**	**1,398**	**1,795**	100%

[1]*OECD member countries (21 of 33), indicating a large degree of developed countries*

Table 11. Converting from Issuer 'Industry' to Sector

Sector	BCLASS Level 3
Supranational	Supranational
Government Agency	Government Owned, No Guarantee Local Authority Banking Government Guaranteed Treasury Mortgage Assets Sovereign Government Sponsored
Financials	Banking Mortgage Assets Government Sponsored Local Authority Government Owned, No Guarantee Insurance Public Sector Loans Other Financial
Corporate Utilities	Other Utility Electric Government Owned, No Guarantee Natural Gas Local Authority
Corporate Other	Technology Consumer Non-Cyclical Basic Industry Consumer Cyclical Other Industrial Government Owned, No Guarantee Capital Goods
Corporate REIT	REITs Consumer Cyclical Other Industrial

Bloomberg Level 3 Industry Classifications converted into six Sectors used as issuer classifications in this study. Some BCLASS Level 3 classifications occur across sectors due to qualitative assessments, for example: Unibail Rodamco Sverige is classified as "Other Industrial" in BCLASS Level 3, however the firm's primary operations relate to real estate (Corporate REIT sector)

Table 12. Test for Multicollinearity

Variable	VIF	Degree of Multicollinearity
Rating	2.62	Low
Institutional	2.78	Low
Sector	2.01	Low
Corwin Schultz Estimator	1.38	Low
Modified Duration	1.28	Low
Currency	4.61	Moderate
Amount_USD	1.31	Low
ECB	1.1	Low
Bid-Ask Spread	1.05	Low
Green	1.04	Low
Green x Year	2.81	Low
Mean VIF	**1.99**	

Table 13. Tests for Heteroskedasticity

	Test	H_0	$\chi 2$	p-value	Heteroskedasticity
Model 1	Breusch-Pagan	Constant σ	328.65	0.0000	Yes
Model 2	Modified Wald	$\sigma_i^2 = \sigma^2$ for all i	4.2e+05	0.0000	Yes
Model 3	Breusch-Pagan	Constant σ	327.86	0.0000	Yes
Model 4	Modified Wald	$\sigma_i^2 = \sigma^2$ for all i	3.4e+05	0.0000	Yes
Model 5	Modified Wald	$\sigma_i^2 = \sigma^2$ for all i	5.1e+34	0.0000	Yes

Table 14. Tests for Autocorrelation

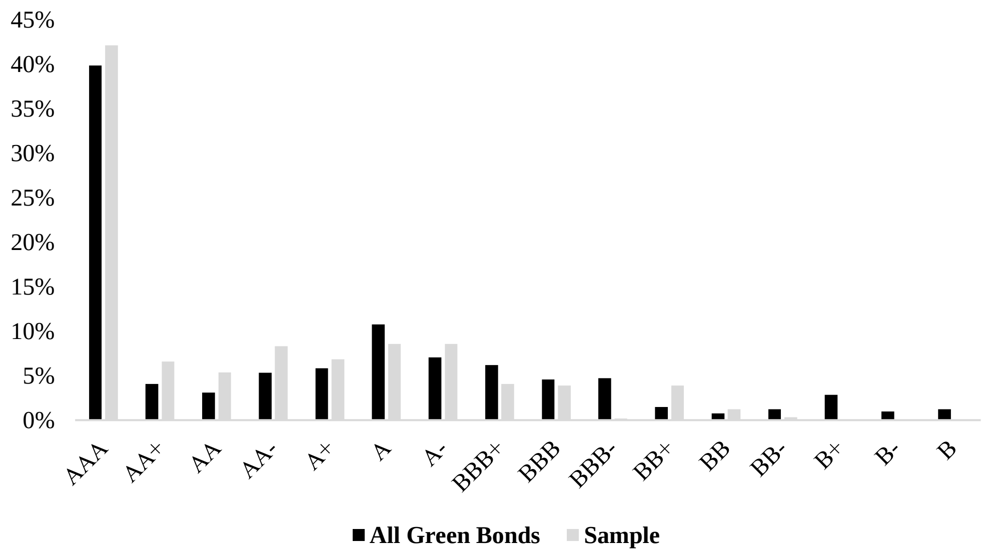
	Test	H_0	χ^2 / F-stat*	df	p-value / Prob. > F*	Autocorrelation
Model 1	Breusch-Godfrey	No serial correlation	1.107	1	0.2928	No
Model 2	Wooldridge	$\sigma_i^2 = \sigma^2$ for all i	2.904*		0.1393*	No
Model 3	Breusch-Godfrey	No serial correlation	1.119	1	0.2901	No
Model 4	Wooldridge	$\sigma_i^2 = \sigma^2$ for all i	2.835*		0.1432*	No
Model 5	Wooldridge	$\sigma_i^2 = \sigma^2$ for all i	0.537*		0.5975*	No

Table 15. Currency Definitions

ID	Currency
AUD	Australian Dollar
BRL	Brazilian Real
CAD	Canadian Dollar
CHF	Swiss Franc
CNY	Chinese Yuan
EUR	Euro
GBP	Great British Pound
HKD	Hong Kong Dollar
INR	Indian Rupee
JPY	Japanese Yen
MXN	Mexican Peso
MYR	Malaysian Ringgit
NOK	Norwegian Krone
NZD	New Zealand Dollar
RUB	Russian Ruble
SEK	Swedish Krona
TRY	Turkish Lira
USD	United States Dollar
ZAR	South African Rand

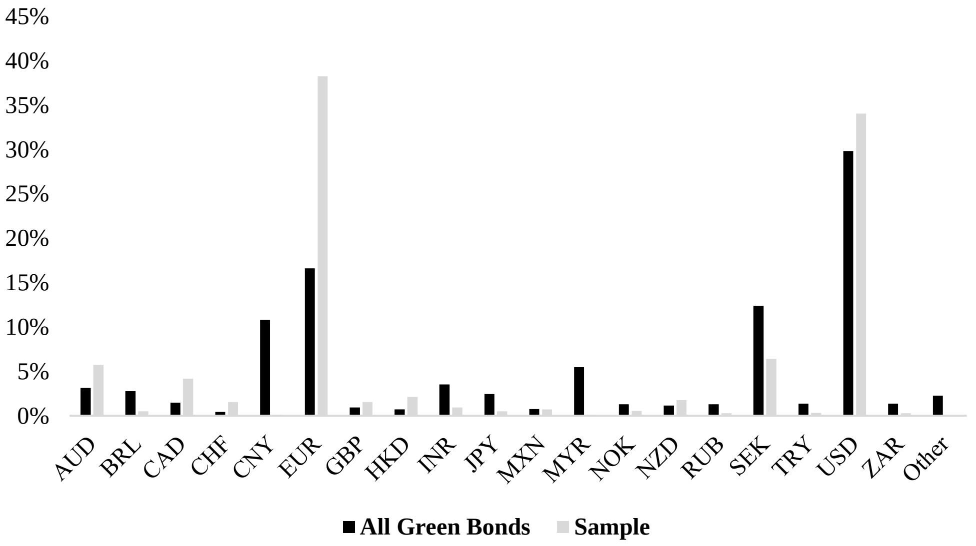
Figures

Figure 3. Sample Representativeness: Ratings[1]



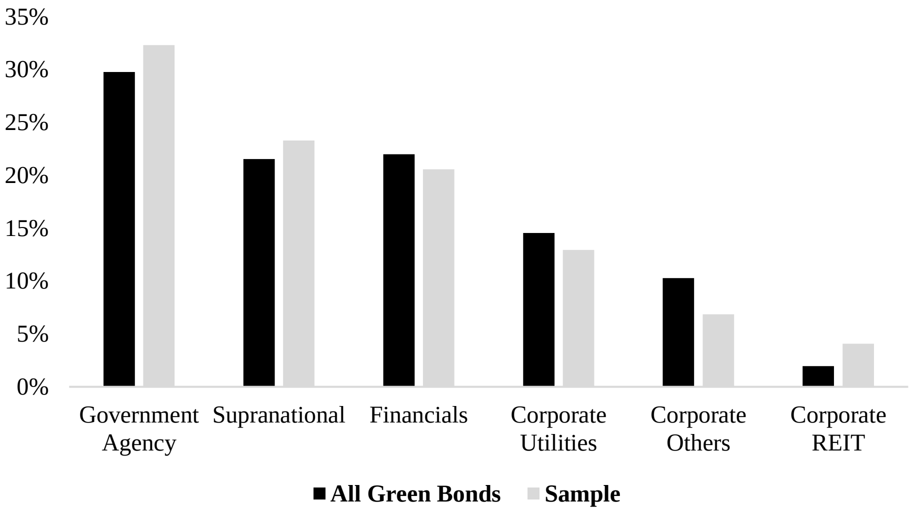
Study sample distribution compared to total labelled green bond universe available through Bloomberg, issued between 2010 and 2018, 1,795 bonds. Graphs are included to indicate the generalizability of the study. [1]56.3% of total labelled green bond universe are not rated and thus excluded from this comparison, largest differential is 4.5%, found in B-rated bonds.

Figure 4. Sample Representativeness: Currencies[1]



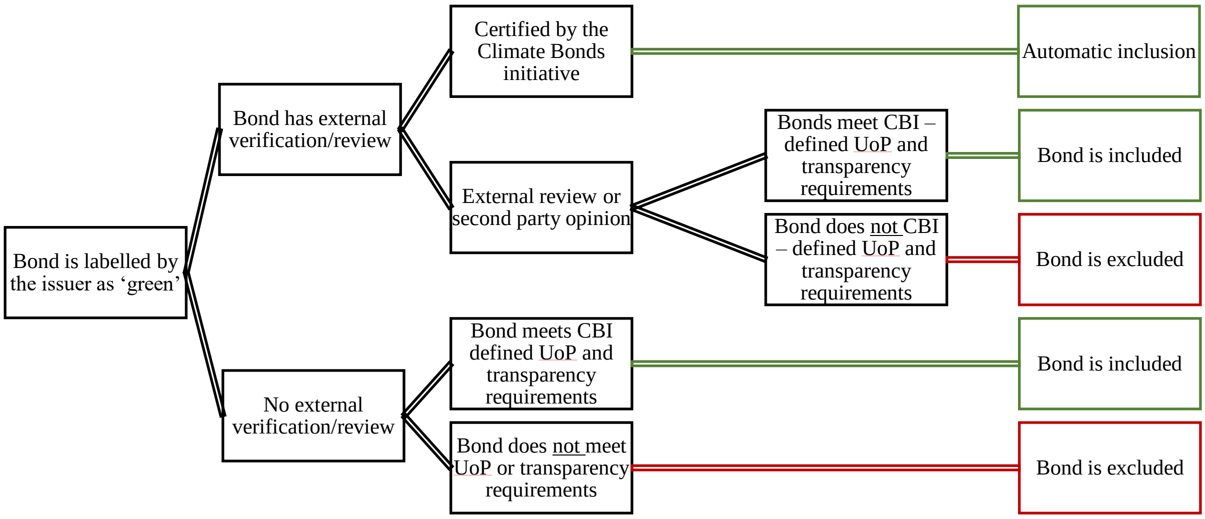
[1]Biggest differential is 21.7%, found in EUR. Due to lack of data for bonds denominated in currencies such as CNY and MYR.

Figure 5. Sample Representativeness: Sector[1]



[1]Modified sectors based on Bloomberg Class Level 3 classification. Biggest differential is 3.4%, 'Corporate Others'.

Figure 6. Green bond database inclusion process



Overview of the rigorous green bond database inclusion process, generating our sample's labelled green bonds collected from Bloomberg. Source: Climate Bond Initiative (2018)