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Interest Rates and their Differential Effect on the Pricing of Green and Conventional Bonds

An empirical analysis of the Nordic and US bond market from 2017-2023

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Abstract

Financial markets play a significant role in the transition towards a net-zero economy. Recent events, specifically the pandemic and Ukraine conflict, have been drivers for increased volatility in financial instruments, mainly due to rapid and frequent changes in interest rates. This study investigates how these interest rate fluctuations impact the differential pricing of green and conventional bonds, and if there exist any regional disparities. By comparing the Nordic and the US bond markets, we find that in the Nordic market, green bonds display greater volatility mainly due to their longer duration. Assuming a successful matching process where each green bond is paired with its closest conventional counterpart, this implies that green bonds posit higher risk in an increasing interest rate environment, which may impact the financial performance of investors. The US market exhibits significantly greater overall volatility due to the higher duration of American bonds; however, no significant differential effect on green bond prices is identified. This indicates that the American bond market is more exposed to interest rate hikes, resulting in a less predictable investing territory. We further document that differences exist between the two regions regarding size, regulations, and investor preferences, which explains why we see differences in bond performance between these regions.

Keywords – NHH, Master thesis, Finance, Green bonds, Interest rates, Sustainability, ESG

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1. Introduction

In this paper we investigate whether interest rate fluctuations have any differential effect on the pricing of green and conventional bonds. This topic is especially relevant for investors and portfolio managers, as it gives insights into the relative risk-return characteristics of green and conventional bonds. In addition, green bonds are a relatively new financial instrument, and the existing literature on interest rates and the comparable pricing of green and conventional bonds needs expansion. Our initial expectation was that green bonds were to be more resilient to interest rate fluctuations due to the increasing demand for sustainable investments, however, our findings suggest the opposite. Moreover, we expect there to be differences in bond pricing between the included regions due to differences in bond characteristics, investor demand and interest rate policies.

To examine this relationship, we compare the Nordic and the United States (US) bond markets. The decision to compare the Nordic and US is primarily driven by our hypothesis that there are substantial differences in investor demand for sustainability as well as noticeable variances in interest rate policies between these regions. In addition, the lack of research examining these two markets specifically further enhances the relevance and interest of this topic. As the two markets hold different characteristics, the goal is to use these two markets to identify any region-specific effects that is due to differences in demand, investor preferences, sustainability policies, or other bond-specific characteristics that differ between the two regions.

We perform a matching technique known as a model-free, or direct, approach (Zerbib, 2019). We match each green bond with a corresponding conventional bond, where the ideal situation would be that the bonds exclusively hold identical characteristics, except the green feature. By doing this we ensure that the green and conventional bond are as similar as possible, however, some margins are allowed within some of the matching criteria to get a sufficient sample size.

In the Nordic sample, our findings show a consistent negative coefficient for the relationship between bond prices and interest rates, with an additional negative effect for green bonds. This suggest that green bonds in the Nordic sample are more sensitive to changes in interest rates compared to the conventional bonds. On the contrary, in the US, interest rates appear to have no significant differential impact on the pricing of green versus conventional bonds. These contrasting relationships are effectively illustrated in the figures below.

Figure 1: Predictive margins of bond prices

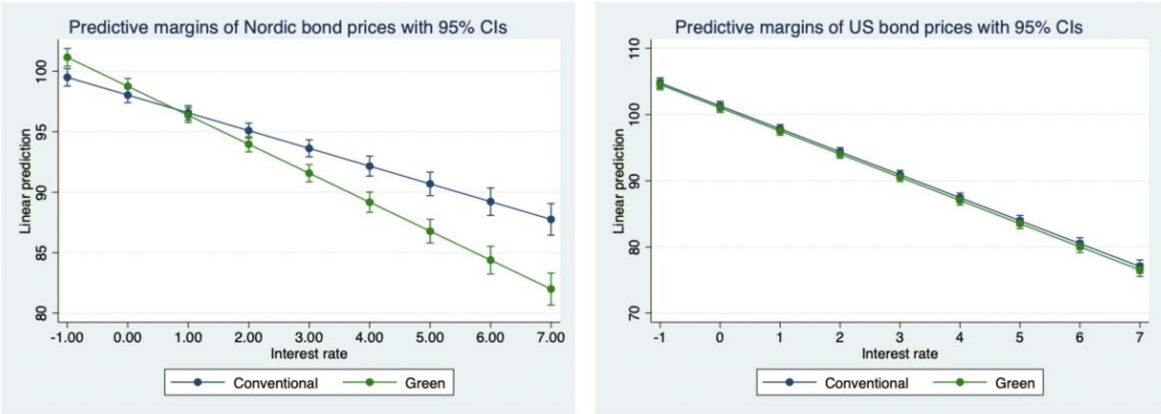

Figure 1 *shows how bond prices move in our two samples when interest rates are increasing. Nordic sample is shown to the left and US sample is shown to the right. This figure effectively illustrates our finding that interest rates have a differential effect on the pricing of green and conventional bonds in the Nordic region.*

We identify that the differential effect between green and conventional bonds in the Nordic sample are mainly due to green bonds on average holding greater duration than their conventional counterparts. We match green and conventional bonds on maturity, however, this is one of the characteristics we allow to vary, which partly explains why the green bond sample holds greater duration. Bos (2023b) identified a one year longer duration for Euro-denominated green bonds compared to their conventional equivalents. Juvyns (2023) also found the green bond market to be more volatile due to greater duration, despite having better credit ratings. This is reinforced by CBI's[1] report from 2022 where they state that green bonds will naturally be more exposed to rising interest rates, mainly due to slightly longer duration (Michetti et al., 2023). As illustrated in the graph above, bonds are generally more volatile in the US market when interest rates increase. The American government implemented more frequent and aggressive interest rate hikes, which subsequently lowered bond prices more. In addition, the American sample holds on average longer maturity and duration than the Nordic sample, which we identify to be the main reason for the excess volatility seen here. However, no differential effect is identified between green and conventional bonds in the US sample.

In the US, just 4% of all corporate bonds issued in 2021 where earmarked green, whilst the comparable number for the Nordic market was considerably higher at 11%. This show that sustainability is not as integrated into the debt capital markets in the US. There is also

[1] Climate Bonds Initiative

increased uncertainty related to ESG[2] investing in the US, where ING[3] (2023) found that 54% of investors in the US expect to see more political pressure and legal actions against the use of ESG investing in the future, while only 35% of the European respondents shared this view. Together, these aspects cause a more complex financial environment to operate in, which could be the cause of there not being a differential effect between green and conventional bonds in the US. It is also worth highlighting that the percentage gap in duration between green and conventional bonds in the US is significantly lower than in the Nordic sample. According to fundamental bond pricing theory, this naturally leads to interest rates having a weaker differential effect on the pricing of these two asset classes in the US compared to the Nordic market.

Our paper employs a methodology that incorporates pooled ordinary least squares (OLS) and time fixed effects (FE) regressions. These models are commonly used when analyzing unbalanced panel data, and similar approaches have been used in similar papers (Bachelet et al. 2019; Flammer, 2021; Zerbib, 2019). By including time FE, we capture the effect of variables that are constant across bonds but vary over time (Schmelzer, 2020). We conduct several robustness tests to increase the reliability and validity of the results, such as F-Test, Wooldridge Test, and Variance Inflation Factor (VIF) test. However, all these tests take certain assumptions and thus has some limitations, which is further discussed in section 4. Furthermore, a difference-in-differences (DiD) including two shocks is implemented to see the effect on bond prices in times of both decreasing and increasing interest rates.

This paper applies the mid-price of the bonds as the dependent variable. This approach controls for some of the skewness in bid and ask prices (Capital.com, 2018). By applying a matching method, we effectively control for numerous variables, as most of them are required to be identical within the matched pairs. In addition, we control for coupon rate, time-to-maturity (TTM), amount issued, and duration to avoid omitted variable bias. Finally, a liquidity proxy is included to control for potential differences in liquidity between the two asset classes and the two regions. The explanatory variables included in these models account for a substantial portion of the variation in bond prices, as indicated by the relatively high R-squared values. However, there may be additional factors influencing bond prices that we have not accounted

[2] Environmental, social, and governance

[3] International Netherlands Group

for in our models. This may be non-measurable factors like investor preferences, market expectations, or sustainability trends.

For the full sample the time FE model suggests that a one percent increase in interest rates leads to a 335 basis points (bps) decrease in bond price, with an additional decrease of 20 bps for green bonds, this effect being captured by the interaction term. For the Nordic region, the findings suggest that a one percent increase in interest rates leads to a 147 bps decrease in bond price with an additional decrease of 93 bps for green bonds. The green bond dummy for the Nordic market also suggests that the pool of green bonds is on average priced 73 bps higher than their conventional counterpart after controlling for other factors. This supports the existing research that finds there to be a greater focus on sustainability in the Nordics than in the US. For the US market, a one percent increase in interest rates leads to a 347 bps decrease in bond prices in general, but no statistically significant effect is captured by the interaction term or the green dummy variable.

Figure 2: *Bond prices over the research period*

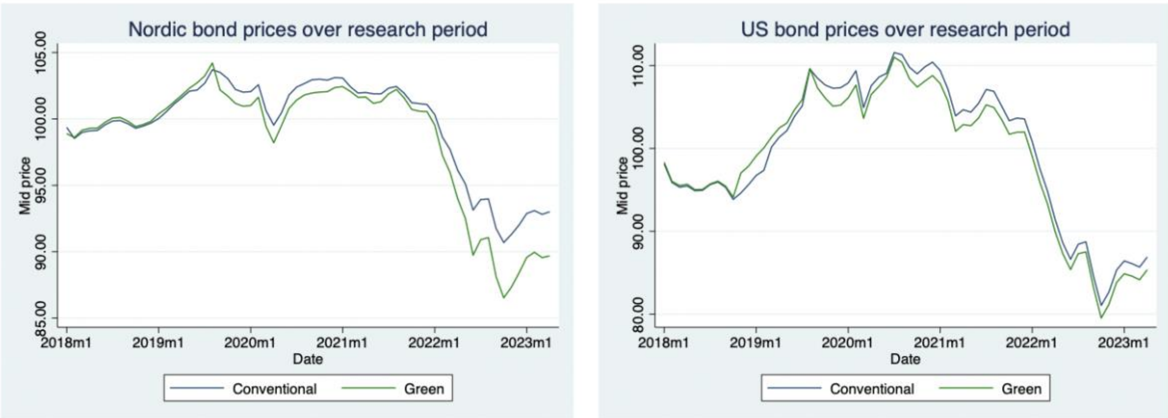

Figure 2 *illustrates the average movements in bond prices for both asset classes across the Nordic and US samples.*

The DiD analysis includes two shocks, one with decreasing interest rates and one with increasing interest rates. The Covid-period is set to March 2020, which was the time governments reduced interest rates to mitigate economic difficulties. The Ukraine-period is set from February 2022 until April 2023, a period with consistent and frequent interest rate hikes across all the included countries. We aim to determine the impacts of these interest rate changes on the relative pricing of green and conventional bonds and identify whether the observed outcomes align with theoretical expectations.

Our findings suggest that during the Covid-period there was an increase in bond prices of respectively 792 bps and 951 bps for the full and American sample. Interest rates decreased, which according to theory should result in increased bond prices, thus the theory matches our findings. The green dummy coefficient is negative for all samples, suggesting that in non-crisis times green bonds are priced lower than their conventional counterparts, holding all else constant. The results from the Ukraine-period indicates that bond prices experience a substantial drop and is statistically significant at the 1% level for all models. This drop stems from raising interest rates and aligns well with expectations and theoretical frameworks. Green bonds in the Nordic sample decrease by an additional 253 bps, the same relationship found in the pooled OLS regressions. As illustrated in Figure 2, American bonds experience excessive volatility, which is due to the US bond sample holding higher duration and the US government implementing more aggressive and frequent interest rate hikes.

One of the main reasons why we want to explore this topic is due to the growing awareness of sustainable investing and all the attention it gets as well as the global trend of increasing interest rates. Global funds all over the world are increasing their portion of green investments in their portfolio and investor demand is changing. Existing research has already studied if there exist a "greenium" in the market. Our initial thoughts were that this growing awareness and the expected increase in demand could lead green bonds to be less sensitive to interest rate changes than conventional bonds. However, we find that green bonds have on average longer duration than their conventional peers, suggesting higher sensitivity towards interest rate changes. We also discuss green investments generally having cashflows longer into the future, also implying higher interest rate risk. For the Nordic market these effects prove to be greater than the demand effect and therefore green bonds are more sensitive to interest rate changes.

2. Background and literature review

This section aims to explain the fundamental concepts regarding green and conventional bonds and interest rates, while also setting the context for further analysis. It highlights the increasing importance of green financing and its potential impact on bond market dynamics. Additionally, existing literature on the topic is presented and assessed.

2.1 Sustainable finance and the transition challenge

The term sustainable finance refers to finance related to ESG factors (Schoenmaker and Schramade, 2019). In general, it relates to green assets, which are intended to generate a positive environmental impact, while brown assets represent the opposite (World Bank Group, 2022). Brown bonds are also denoted as conventional bonds throughout this paper. However, traditional economic models, developed during a time of perceived resource abundance, did not account for factors such as carbon emissions or resource scarcity. Over time, these models became inadequate in addressing the changing demands of society, prompting a shift towards sustainable finance as a central concern for global leaders, governments, and institutions (Schoenmaker and Schramade, 2019). This ongoing transition to a low-carbon and circular economy is particularly relevant, as it increases demand for green assets and subsequently could lead to differences in the comparative pricing of green and conventional bonds. Various policy measures have been implemented to mitigate climate risk, such as the United Nations' sustainability goals and the Paris Agreement (United Nations, 2022). These initiatives have increased the growth of green bonds, as green financing is integral to achieving the outlined objectives.

To mitigate risks and take advantage of new opportunities, investors, banks, and other financial institutions are continuously looking for methods to integrate their operations with sustainability goals, such as issuing green bonds (European Commission, 2021). Merely the increased focus on sustainable finance gives higher potential to the green bond market and its investors. Sustainable finance can also benefit businesses and investors financially, where it is found that investments in more energy-efficient and renewable energy projects can provide attractive returns while reducing climate risk (Pastor et al., 2022).

2.2 Bond pricing mechanisms

Bonds are priced on several factors, including the prevailing interest rates, credit risk of the issuer, coupon rate, and the time to maturity. The general bond pricing equation is given by:

Equation 1: *Bond price with coupon payments (Petitt et al., 2015)*

$$Price = \sum_{t=1}^{N} \frac{Coupon_t}{(1 + YTM)^t} + \frac{FaceValue}{(1 + YTM)^t}$$

Where Price is the price of the bond, Coupon is the coupon payment at time t (coupon rate multiplied with face value), FaceValue is the value that must be repaid at maturity, and YTM is yield-to-maturity which is the actual return for investors if they hold the bond until maturity and it is not defaulted (Corporate Finance Institute, 2022). The bond price represents the present value of all future coupon payments that are expected over the term the bond is issued for. This includes face value, which is repaid at maturity, if the issuer has not defaulted.

The coupon rate is considered the issuer's borrowing cost, as it is the rate that the issuer pays to the holders of the bonds, whereas the yield is the return to the investor. Bonds can either have a fixed coupon rate or a floating coupon rate. The floating rate follows an underlying benchmark rate, such as the money market rate LIBOR[4] (Petitt et al., 2015).

2.2.1 Bond pricing in primary and secondary market

The pricing in the primary market and secondary market is down to completely different mechanisms. When a bond is first issued, it is issued in the primary market where the issuer of the bond is the one that determines the initial offering price of the bond. This is based on several factors, such as current market conditions, credit risk, and overall characteristics of the issued bond (Vanguard, n.d.).

The credit risk of a bond refers to the risk that the issuer fails to repay its obligations, meaning fails to repay coupons or repay the bond at maturity, and thus defaults (Chiţu et al., 2022). Bonds are usually classified after this credit risk, which is done by a rating system where rating

[4] The London Interbank Offered Rate

agencies provide them with a credit rating[5]. There are mainly two classifications: investment-grade or non-speculative bonds, and high-yield or speculative bonds[6]. The risk of default is higher when the credit rating is weaker, however, potential returns are higher. This is a trade-off investors have to consider when investing in bonds.

The secondary market behaves in many ways like a stock market and is where previously issued bonds are bought and sold. The borrowing cost for the issuer is not affected by the bond reselling in the secondary market (Vanguard, n.d.). Market forces such as supply and demand, changes in credit rating, and interest rates have an impact on the bond prices and how they fluctuate (Merrill, 2022). If an issuer experiences a downgrade in their credit rating, this usually results in a drop in price for the bonds trading in the secondary market.

The relationship between bond pricing and interest rates is inverse, meaning that they move in opposite directions. If interest rates rise, bond prices fall, and if interest rates fall, bond prices rise. The reason behind this inverse relationship is that when interest rates rise, the value of existing bonds fall relative to the value of newly issued bonds that offer higher yield to investors. This means that existing bonds with lower yields become less attractive, leading the price to fall. Oppositely, when interest rates fall, newly issued bonds become less attractive to investors as their value relative to existing bonds is worse, leading to a price increase in existing bonds (Lioudis et al., 2022).

2.3 Green bonds

Green bonds are by the International Capital Market Association (ICMA) defined as bonds that enable capital-raising and investment for new and existing projects with environmental benefits (Green Bond Principles, 2021). Examples include renewable energy, energy efficiency, pollution prevention, water management and biodiversity (Bos, 2022b). In 2021, global issuers issued green bonds for over 500 billion US dollars (Harrison et al., 2022). In a recent publication by McKinsey, Kumra and Woetzel (2022) stated that the global economy needs to invest about $275 trillion on physical assets to reach net zero by 2050. This substantial

[5] Credit ratings showed in appendix 4

[6] Investment-grade bonds refer to those with ratings exceeding BBB- or Baa3, while high-yield bonds are those with ratings falling below these benchmarks

investment requirement not only showcases the accelerated expansion of the green bond market but also suggests a notable, expected surge in demand for green bonds towards 2050.

2.3.1 Global principles and certification

As the green bond market has expanded, the need for global guidelines and principles to promote transparency has become vital. Green Bond Principles (GBP), introduced in 2014, provide issuers with guidance on funding environmentally sound and sustainable projects. The GBP requires four key components to certify a bond as green: 1) Use of Proceeds, 2) Process for Project Evaluation and Selection, 3) Management of Proceeds, and 4) Reporting. These components are set to guarantee that proceeds are exclusively allocated to sustainable projects, fostering improved communication between issuers and investors (ICMA Group, 2021). Standards and principles like this help reduce asymmetric information, as it requires companies to provide GBP with the necessary information to receive the green certification.

2.3.2 Challenges facing the green bond market

While the green bond market has made considerable progress since its birth in 2007 (Climate Bonds Initiative, 2023), it still faces challenges that might undermine its credibility, subsequently decreasing demand for green bonds. The lack of standardization in verification and certification, and instances of greenwashing poses challenges for investors when considering green investments. If green bonds are seen as less credible due to greenwashing or lack of standardization, investors may want to look for other investing opportunities, reducing demand for green assets. On the other side, if the green bond market addresses these concerns through further development of standards and certifications, it may strengthen the appeal for green bonds as a viable investment option (Doran & Tanner, 2019).

The recent increase in interest rates has also become a key worry for global investors, as central banks worldwide strive to control inflation. Lee Clements, head of Applied Sustainable Investment Research, states that the extent of interest rate rises will play a critical part in funding the climate transition. He also emphasizes that there is a growing awareness regarding whether central banks should take climate risks into account when differentiating their interest rate policies. This creates a complex dilemma for central banks where they have to balance economic concerns and climate risk (Clements, 2022).

2.4 Interest rate evolvement over the research period

Governments make changes to interest rates when they are trying to influence and stabilize the economy during uncertain times (Norges Bank, 2003). These adjustments play a crucial role in understanding the pricing dynamics of the two asset classes. Governments typically interfere when certain events occur, or some economic or financial challenge is met. Such events could be the financial crisis in 2007-2008, the sovereign debt crisis in the European Union (EU) in 2010-2012, or events like the recent pandemic and the war in Ukraine.

Figure 3: Global issuance of ESG bonds

Figure 3 *shows the global volumes of green, social, sustainability, sustainability-linked, and transition bonds in 2022* (Michetti et al., 2023).

The recent pandemic had a significant impact on the bond market overall. There were some differences in performance between the conventional bond market and the green bond market, as some studies found green bonds to be more resilient and stable, mainly due to higher demand (Hacıömeroğlu et al., 2022). Central banks all over the world lowered interest rates to near zero-levels, which lowered yields on bonds making them less attractive for investors. In some cases, central banks offered negative interest rates to stimulate the economy (Koulouridi et al. 2020). This further led to increased uncertainty in financial markets leading investors to move their money to higher rated bonds (Norges Bank Investment Management, 2021). This increased demand for these bonds, driving the price up. In addition, the pandemic accelerated the growth of the green bond market. It highlighted the importance of green and sustainable investing which increased both the supply and demand for green bonds (Mehta et al., 2021).

2.4.1 Interest rate risk

Interest rate risk in bonds is the possibility of a loss that could result from a change in interest rates. Changes in interest rates has a direct effect on bond prices and is seen as a major risk to all bondholders. The change in a bond's price due to interest rate changes is called duration, and is higher for longer maturities (Capital.com, 2020). In terms of interest rate risk, fixed income investors are facing two offsetting types of risk, price risk and reinvestment risk. These two impacts will precisely cancel each other out if the portfolio duration is properly chosen. Price risk refers to the potential decrease in the market price of a bond, while reinvestment risk refers to the risk that an investment could provide lower expected returns due to declining interest rates (Bodie et al., 2018).

Duration is a measure which accounts for the bond’s time to maturity and the bond’s coupon rate. The estimated durations retrieved from the Bloomberg terminal is respectively 6.92 for the Global Green Bond Index, and 6.12 for the Global Aggregate Corporate Index. This suggests that the green bond market is more sensitive towards interest rates changes than the conventional bond market. Bos (2023b) identified a one year longer duration for Euro-denominated green bonds (Bloomberg MSCI Euro Green Bond Total Return Index) than the non-green equivalent (Bloomberg EuroAgg Total Return Index) and stated that the reason was largely because of sovereigns such as the EU issuing bonds with longer maturity at times of low interest rates. As 63% of the outstanding green bond market are issued in Euros, it is reasonable to say that this will influence the global green bond market as well.

Recently, Silicon Valley Bank (SVB) were taken over by the government as they faced the price risk, meaning that the value of the bonds was exposed to the risk of interest rate changes. The bank had benefitted from a period of low interest rates, and money had been poured into the bank through huge investments in tech companies. A substantial portion of this money were then put into long-term US treasuries with fixed coupons. Post-covid, this poses a major risk as central banks raised interest rates to stabilize the economy. The bonds SVB held then fell in value relative to newer issued bonds, as well as depositors of the bank required higher returns. SVB[7] then had to sell parts of these bonds, at a significant loss (Helmore, 2023).

2.5 Nordic and US bond markets

To investigate whether interest rates have any differential effect on the pricing of green and conventional bonds, this paper assess the Nordic and US bond markets. By doing so, we aim to identify any potential regional differences in how interest rates influence the pricing of these two asset classes. As the two regions hold different characteristics, and differences in the economic environment they operate in, there are multiple reasons as to why they might perform differently.

2.5.1 The Nordic bond market

The Nordic bond market encompasses debt instruments issued by businesses and governments in Denmark, Finland, Iceland, Norway, and Sweden. Norway and Sweden dominate the market, accounting for about 90% of both new issue volume and the total outstanding volume of green bonds (Nordic Trustee, 2023). The Nordic green bond market primarily features corporate issuers from industries such as energy, transportation, and real estate, with 79% of corporate green bonds considered investment-grade (Nordic Trustee, 2023). The Nordic market is regarded one of the most developed and liquid bond markets and is distinguished by a high degree of transparency, stability, and investor confidence (Nordic Investment Bank, 2021). Strong investor demand has fueled the Nordic region's green bond market, as they are becoming increasingly interested in incorporating environmental and social factors into their investing plans.

2.5.2 The US bond market

Similar to the global green bond market, the US green bond market has grown significantly in the last few years. With a wide variety of issuers and investors, the US green bond market has proven to be the biggest green bond market in actual issuance size[8] (Harrison & Muething, 2021). Since the US green bond market’s establishment, buildings have dominated the use of

[7] SVB collapsed on March 10, 2023, and was the biggest collapse since Washington Mutual collapsed in 2008

[8] See appendix 1 for total issuance of green bonds by country in 2021

the proceeds category, followed by renewable energy and water. Compared to the Nordic green bond market the US market is able to have a more diversified range of eligible projects due to the size of their market.

2.5.3 Why compare the Nordic and US bond markets

The reasons for why the two markets might perform differently to interest rate changes can be divided into two main categories, namely demand-related factors, and liquidity-related factors. Europe, including the Nordics, has been the main driving force in the development of the green bond market. However, it is expected a regional shift in the Europe-dominated market, with a growing share of American issuers (Wass et al., 2023). The European dominance is strengthened by euro-denominated bonds holding 63% market share of the green bond market, whereas the overall bond market is largely denominated by US dollars (Bos, 2023a). In the US, 95% of all green bonds were issued in US dollars in 2021. The absence of currency diversification implies a developed and established domestic bond market (Harrison & Muething, 2021). Further, there exists a currency risk premium depending on which currency bonds are issued in (Schmukler & Servén, 2002), which can have a differential effect on the Nordic and US bond market. If an investor's domestic currency strengthens against the issued bond's currency, the bond's interest payments and principal, when converted back to the investor's domestic currency, will be worth less. This would lead to the investor demanding a higher yield, and therefore a lower price, to compensate for this additional risk.

In the Nordic bond market, green bonds are more integrated into the debt capital markets, as the relative share of green bond issuance is higher. In the US, approximately 4% of all corporate bonds issued in 2021 where earmarked green, whilst the comparable number in the Nordics are 11% (Albuquerque, 2023; Nordic Trustee, 2023; SIFMA, 2023; Statista, 2022b). This implies a stronger supply-side of green bonds in the Nordic countries, which has to be matched by sufficient demand to keep competitive bond prices.

Monetary policies and inflation expectations in the two regions differ somewhat as well. Both regions have been subject to increasing inflation, where central banks have raised interest rates to deal with inflation (Danske Bank, 2023; Paul, 2023). The recent interest rate hikes in the aftermath of the Covid-19 pandemic have followed roughly the same pattern in the Nordic and US markets. However, the US implemented more aggressive and frequent increases in interest rates. As interest rates are an important aspect in bond pricing, there are potential differential effects in bond pricing in the two regions, where bonds in the US could see greater volatility.

Additionally, the two regions have different focus on sustainability, and different level of sustainability incorporated throughout their respective economies. The Global Competitiveness Index is the most comprehensive sustainability index measuring countries based on multiple indicators. The Nordic countries hold five of the top six spots in the 2022 ranking, whilst the US rank in 30th place (SolAbility, 2022). This can be an indication of investors and companies' view on sustainability and could subsequently impact bond pricing. Further, the regulatory environment regarding sustainability in the US and Nordics is not the same. The Nordic countries have made a joint agreement to aim to become the most sustainable and integrated market in the world by 2030, which requires strict regulation and reporting requirements (Nordic Cooperation, n.d.). This could further increase the distance between the US and Nordic countries regarding sustainability and increase demand for green assets in the Nordic countries, subsequently making the green bond market more liquid.

2.6 Existing literature

Existing literature on this topic has primarily focused on the general performance and risk characteristics of green compared to conventional bonds. Several studies investigate whether there exists a "greenium" in the bond market (Larcker & Watts, 2020; MacAskill et al., 2021; Pietsch & Salakhova, 2022; Zerbib, 2016), but we intend to explore this topic from a different perspective. The "greenium", or green premium, refers to pricing benefits based on that investors are willing to forego financial reward by either paying extra or accepting lower yields in exchange for sustainable impact (D'incau et al., 2022). There is limited research specifically addressing the relationship between interest rate fluctuations and the pricing of these two bond types. Previous studies have also explored the drivers of green bond market growth, the determinants of green bond pricing, and the influence of ESG factors on bond performance (Hachenberg & Schiereck, 2018; Flammer, 2021; Stellner et al., 2015; Tang & Zhang, 2020).

2.7 Literature review

This literature review aims to present an overview of the current research, theories, and empirical findings on the relationship between interest rate fluctuations and components of bond pricing, with a particular focus on the distinction between green and conventional bonds.

2.7.1 Components of bond pricing

Merton's (1974) foundational work on bond pricing identifies three primary factors affecting bond prices: the bond's underlying characteristics, the risk-free rate, and default or credit risk. However, subsequent research has expanded on Merton's framework to address the influence of other factors, such as default before maturity and changing interest rates, which may have important implications for the stability and efficiency of green bonds compared to conventional bonds. For instance, Eom et al. (2004) find that structural models have limited success in explaining variation in corporate bond prices, particularly for investment-grade bonds, as they generally underestimate bond credit spreads. Their research highlights the significance of firm-specific characteristics and credit ratings in determining bond prices.

Huang and Huang (2012) reinforce the idea that credit risk only accounts for a small portion of the credit spread. They found that less than 25% of the credit spread is explained by credit risk, indicating that other factors such as the greenness of the bond can have an impact on bond pricing, potentially leading to differences in the relative performance of green and conventional bonds. Petitt et al. (2015) argue that maturity, credit risk, and liquidity are essential factors to consider when assessing bond pricing and suggest that bonds with longer maturities should include a maturity premium due to increased risk and uncertainty when having a longer investment horizon. The concept of a liquidity premium, supported by Dick-Nielsen et al. (2012), is also relevant to the comparison between green and conventional bonds, as liquidity preference hypothesis suggests that the term premium increases with maturity (Ornelas & Silva, 2015).

2.7.2 Green bonds and its premium

Flammer (2021) recently published a paper examining corporate green bonds and identifies three potential motivations for issuing green bonds: signaling effect, greenwashing, and cost of capital. The signaling effect refers to a company's desire to credibly signal its environmental commitment, while greenwashing involves companies portraying themselves as environmentally responsible without taking meaningful actions. The cost of capital argument suggests that companies may issue green bonds to obtain cheaper financing. Flammer finds that green bonds serve as a credible signal of a company's environmental commitment and attract more long-term, environmentally conscious investors. However, she does not find a significant pricing difference between green and conventional bonds, which contradicts the cost of capital argument. Larcker and Watts (2020) also concluded that there is no pricing difference when analyzing the green municipal bond market.

There is not broad agreement on how sustainability and ESG factors impact green bond prices. Hachenberg and Schiereck (2018) highlight that most research on this topic suggests that ESG-aligned financial instruments perform better than their non-ESG counterparts. Fatica et al. (2021) also find that companies with high environmental performance benefit from lower cost of debt. Despite this, other studies have found the opposite results. Zerbib (2016) found a small average negative green bond premium and emphasizes the importance of industry and credit rating as drivers of the green bond premium.

Some studies argue that there should not be any price differential between green bonds and comparable conventional bonds. Schoenmaker and Schramade (2019) state that green bonds should have the same risk profile as other bonds issued by the same issuer with similar characteristics. This is supported by Morgan Stanley’s (2017) findings that, after controlling for industry, curve, and currency, most green bonds can be purchased at similar yield spreads as conventional bonds. Green assets have also been found to be perceived as less risky by investors (Krüger, 2015).

2.7.3 Interest rate risk and green bond market performance

Standard bond pricing theory suggests that the relationship between interest rates and bond yields are strongly interconnected. When interest rates rise, so does bond yields, and vice versa. A paper by Campbell et al. (2009) researched the relationship between inflation-indexed bonds and interest rates prior to the 2008 financial crisis. These bonds differ from green and conventional bonds in the sense that they are constructed to hedge inflation risk, but apart from this they behave in the same way. They found that when interest rates decrease, so does the yield of the inflation-indexed bonds, which is consistent with general bond pricing theory. This interest rate risk is absent in times where interest rates are constant over time.

Another study, published by Barua and Chiesa (2019), specifically looks at green bonds and what affects the funding size. They argue that the prevailing market interest rate has no significant effect on issuance size when companies issue green bonds and concludes that this is consistent with existing literature on the topic. This indicates that interest rate changes should not affect supply of green bonds, however, it might have an impact on the pricing of these bonds. This originates from standard bond pricing theory which suggest that when interest rates increase, the pricing of bonds declines, and vice versa.

In a paper by Amiraslani et al. (2021), they find that debt investors believe high corporate socially responsible (CSR) firms are less likely to engage in detrimental actions, such as asset substitution or diversion, that could negatively impact bondholders. They also saw that high-CSR firms were able to raise more debt at more favorable interest rates and better credit ratings. Further, a report by the European Commission (2016) argues that companies struggle to obtain as good credit rating on their green bonds as they would on their conventional bonds. This lower credit rating increases the cost of financing, complicating the process of green bond issuance for these companies.

Juvyns (2023) recently did a study on how well green bonds perform in the fixed income market and performed similar matching criteria as this paper with some exceptions. He collected data on 160 pairs of green and conventional bonds, 99 euro-denominated and 61 USD-denominated. He compares Bloomberg Global Aggregate Index and the Bloomberg MSCI Global Green Bond Index. He discovers that although the green bond index has a higher credit quality than its non-green equivalent, it has been underperforming and proved to be a more volatile market. He identified this to mainly be because of the higher duration seen in green bonds.

CBI stated in a report published in 2022 that central banks are closing off the post-pandemic support and higher interest rates are expected. This naturally causes investors to be more cautious as their investments face increased interest rate risk. Further, they stated that green bonds naturally would be more vulnerable to the rising rates due to slightly longer duration. However, they also state that there are some uncertainties here due to the increasing demand for sustainable investments that might offer other benefits (Climate Bonds Initiative, 2022).

2.7.4 Mechanisms in the Nordic and US bond markets

Previously we discussed that the two regions hold different characteristics in terms of investor demand and market liquidity. We also mentioned differences in currency, green bonds being more integrated in Nordic debt markets, and differences in monetary policies, inflation expectations and sustainability focus.

Deschryver and De Mariz (2020) observed some significant differences between American and European investors. Their findings revealed that European investors typically apply more stringent criteria in their green investing strategies compared to their American counterparts. Since this comparison was discovered between the US and Europe as a whole, one could reasonably assume that these differences may be even more significant if the comparison was made specifically with the Nordic region. This is based on the Nordic region's reputation as one of the areas with the highest focus on sustainability in Europe.

A recent study by ING compared the progress of the US and Europe in terms of ESG practices and climate policies. The findings suggest a more advanced approach by the European Central Bank, with the large banks in Europe being more willing to take responsibility in this shift compared to their American counterparts. The study also incorporated a survey, asking the respondents if they expect to see more political pressure and legal actions against the use of ESG investing in the domestic market in the future. The results revealed a notable disparity between the two regions; while 54% of US respondents agreed with this statement, only 35% of the European respondents shared this view. This implies a higher degree of uncertainty surrounding green investment and climate finance policies in the US compared to Europe (Nordic region being highly comparable to Europe) (ING, 2023).

CBI’s global sustainable debt report (Michetti et al., 2023) identifies that the US and European green bond markets also display differences in terms of average deal size and tenor. Europe exhibits larger deal sizes on average, while the duration of deals, or tenor, tends to be shorter than the comparable deals in the US. Long et al. (2022) also recently published a paper examining the spillover effects between uncertainties and green bond markets in the US, Europe, and China. They discovered that the US green bond market is dominant as it consistently transfers spillovers to other green bond markets. The relationship between US and Europe was significantly higher than the relationship with China mainly due to differences in market maturity, proportion of experienced institutional investors, and the market volume of green bonds.

2.8 Research question

The previously described literature triggered our interest on this topic. However, the gaps in the existing literature made us curious about how interest rate changes impact the pricing of green and conventional bonds, and if there are any significant differences in pricing between the two bond markets. This led us to the following research question:

> *The recent fluctuations in interest rate will have a bigger impact on the pricing of conventional bonds than green bonds, making the green bond market more resilient to interest changes.*

There are several suggestions as to why there might exist pricing differences between these two asset classes. One aspect to consider is the growing awareness about the necessity of sustainable practices to help achieve a net-zero economy by 2050 and the substantial growth prospects associated with this shift. Naturally, an increase in demand for these sustainable assets is expected to influence their pricing. Bos (2023b) also states that the Ukraine war has led to a surge in energy prices and motivated European countries to diminish their reliance on Russian oil and gas. This situation is making renewable energy sources increasingly attractive.

Other reasons for why one can expect higher demand for green bonds are the attractive investor contribution towards achieving the goals set by the Paris Agreement and the United Nations' Sustainable Development Goals (SDGs). Nowadays, non-financial performance is more commonly evaluated when making investment decisions, with up to 90% of investors stating that ESG performance is a critical factor in their investment strategies (Bell, 2021).

Furthermore, replacing a portion of a conventional fixed income portfolio with green bonds with similar characteristics could provide lower credit risk over time, through the funding of green projects. An increased portion of green bonds in the portfolio may also serve as an effective hedge against climate change-related risks, stemming from policy shifts such as the introduction of carbon taxation (Bos, 2023c). By issuing green bonds, it may lower the interest rate paid on the bond relative to their conventional twins. In addition, issuing green bonds might attract new investors that are interested in sustainable investments, which in turn increase demand (Caramichael & Rapp, 2022). Several studies have also found that green bonds outperform traditional bonds in times of crisis (Hacıömeroğlu et al., 2021; Ramel & Michaelsen, 2020).

Contradictory, we know that on average the green bond market has higher duration than the conventional bond market. The isolated impact of this factor suggests a higher sensitivity to interest rate changes for green bonds compared to conventional bonds. However, the magnitude of this effect compared to the effect of increasing demand for green bonds remains unclear, as existing research have not sufficiently addressed this question. This research becomes particularly relevant, given the current economic situation where increasing interest rates has become a global trend in the aftermath of the pandemic.

Another argument as to why green bonds might be more impacted by interest rate changes is the fact that the cash flows of green projects lie further into the future. These projects are not the most financially profitable currently compared to alternative investment opportunities, and investors are aware of this. This can create a level of uncertainty among investors, as the time frame for when these projects will start generating cash flows remains unclear. In periods of economic instability or fluctuating interest rates, investors might be more prone to selling their green assets first. This could heighten green bonds’ sensitivity to interest rate changes, and subsequently increase their duration.

Regional differences may also exist in the responsiveness of how green bonds react to interest rate changes compared to conventional bonds. In this paper, we focus on the Nordic and US bond markets to investigate whether interest rates fluctuations have a differential effect on the two asset classes in these two markets. Based on this we investigate a second hypothesis:

> *The differential effect of green and conventional bonds to interest rate fluctuations is anticipated to display greater differences in the Nordic bond market compared to the US.*

Even though the two bond markets are among the most developed they still have some different characteristics that may result in different responses to interest rate changes. Differences in sustainability focus, investor demand, monetary policies, and market liquidity may result in interest rates having a differential effect on the pricing of the two asset classes.

3. Data retrieval, matching methodology, liquidity proxy, and data description

The primary objective of this paper is to investigate the differential effect interest rates has on green and conventional bonds. We collect data on bonds from 01.01.2017 until 20.04.2023 in the secondary market and are limiting our research to the Nordic and US bond markets. This section goes through the process of data retrieval and cleaning and elaborates on the matching technique used to pair each green bond with a conventional bond. The descriptive statistics of our data is also presented to give an impression of the data and what characteristics it holds.

3.1 Data retrieval and cleaning

We identify the relevant bonds in our sample through the Bloomberg Terminal and Stamdata's database. We got external help from the Norwegian investment bank Arctic Securities to collect parts of the data. We collect historical bond prices and bond characteristics for the matching method as well as historical interest rates for the Nordic countries and the US using the Bloomberg Terminal. We use monthly bond prices for the analysis.

We find no matches of green and conventional in the Nordic market before 2017, making this the starting point of our analysis. We use the same search specific criteria for both the Nordic market and the US market. We specify our search to corporate bonds only, as the impact of interest rates on pricing will be more significant here due to generally weaker credit ratings. The bonds need to have either Moody's or S&P's credit rating available on Bloomberg, as this is one of the criteria in the matching method. We also limit our search by excluding bonds that miss data on bid and ask prices, amount issued, coupon rate, duration, and International Securities Identification Number (ISIN).

Previous research has limited their search to fixed rate bonds only (Bachelet et al., 2019; Flammer, 2021; Zerbib, 2019). These studies focused on the green premium and green bond characteristics. We wanted to include both fixed rate bonds and floating rate bonds to increase our sample size. In general, bonds with floating coupons have less interest rate sensitivity than bonds with fixed coupons. This is simply because bonds with floating coupons follows an underlying reference rate (such as Norwegian Interbank Offered Rate, NIBOR), where the coupons get adjusted periodically. When interest rates change, so does the coupons on bonds with floating rate, and the yields stay more in line with the prevailing market rates. Therefore, bonds with floating rates are excluded from the analysis as the effect of interest rates on pricing is less impactful for these bonds.

These search limitations result in 173 green bonds and 1 179 conventional bonds for the Nordic market, and 253 green bonds and 14 780 conventional bonds for the US market. To identify if a bond were categorized as green or not, we used the "Green instrument indicator" in the Bloomberg Terminal which indicates "yes" for the green bonds and "no" for the conventional bonds. For Bloomberg to label a bond as green is either when an issuer 1) self-labels its bond as 'green', or 2) identifies it as an environmental sustainability-oriented bond with clear intentions of using the funds towards projects and activities in line with the GBP (Green Bond Principles, 2017).

3.1.1 Interest rates

The interest rates in the countries included in the research follow roughly the same pattern. When Covid-19 hit the global news, all central banks lowered the interest rates close to zero as most of the society and businesses had to shut down operations. During the latter part of 2021 and the start of 2022, central banks started to raise interest rates again and has now reached a relatively high level in an attempt to control inflation. It is during these periods of market fluctuations that bond prices experience the most significant impact. The US implemented slightly more aggressive and frequent interest rate hikes, which could lead to greater volatility in US bond prices compared to Nordics.

Figure 4: Interest rates over the research period

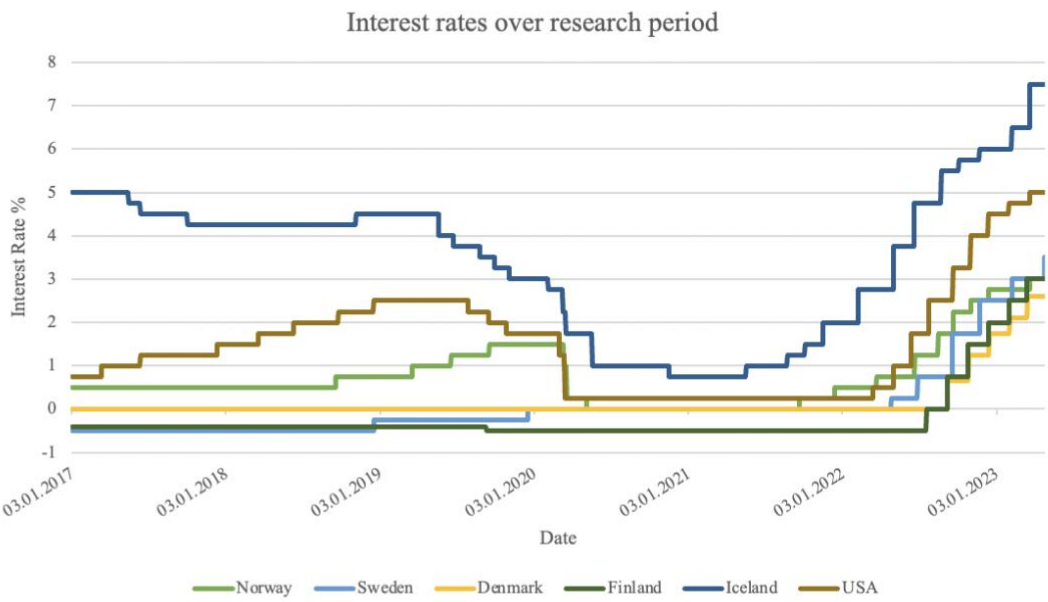

Figure 4 *shows interest rates for the Nordics and the US from January 2017 to April 2023* (Bloomberg, 2023).

3.1.2 Bid and ask price

Bid and ask prices are two of the parameters we use to assess the relative performance of green and conventional bonds. The bid price is defined as the highest price a buyer is willing to buy for a specified number of securities at any given time. The ask price is defined as the lowest price at which a seller is willing to sell the securities. The difference between the bid and ask price is called the bid-ask spread (U.S. Securities and Exchange Commission, n.d.).

Bid and ask prices for bonds are impacted by multiple factors and market conditions, such as interest rates, supply and demand, and overall market liquidity. If interest rates change, then the attractiveness of bonds compared to other fixed-income securities may change. When interest rates rise, newly issued bonds offer higher yields, increasing demand for these bonds. This results in lower bid prices and wider bid-ask spreads. In general, economic uncertainty can also have an impact on bid and ask prices. Investors might prefer to hold safer fixed-income securities during times of economic instability, resulting in higher demand and higher bid prices for these assets. Finally, the basic principles of supply and demand can also have an impact, as higher demand usually increase bid prices, and subsequently narrows the bid-ask spread.

The relationship between bid and ask prices and market liquidity is strongly interconnected. When a market is liquid, meaning there are many buyers and sellers willing to trade bonds, the bid-ask spread is normally tighter. In a scenario with an illiquid market, there is usually a larger difference in bid and ask prices, resulting in a wider bid-ask spread (Petitt et al., 2015).

3.1.3 Sample duration

We estimate the average duration of the green and conventional bonds for both the Nordic and American bond markets using the Bloomberg terminal. The duration for green bonds in the Nordic market is 3.49 and the comparable duration for conventional bonds is 2.75. For the American market the average duration of the green bonds in our sample is 8.03 and the comparable duration for conventional bonds is 7.59. This indicates that in general, green bonds are more sensitive to interest rate changes in both regions. In addition, the US have substantially higher duration than the Nordic market, indicating higher volatility for bonds during times of interest rate changes.

3.2 Matching method

A matching methodology is implemented, as it incorporates relevant variables that might have different impact on bond prices, making the regression less biased. Also, since bid and ask prices are not independent of each other, we control for several variables to avoid omitted variable bias. Bonds that miss data on certain criteria or prices are excluded from the sample. We also exclude bonds issued by companies being green in nature, meaning that they exclusively issue green bonds and thus no conventional counterpart is identified.

The matching methodology used in this paper is one of the most common used in bond matching. The ideal situation for this kind of analysis would be to have two identical bonds, except for one being "green" and one being "not green". This would mean that the bonds should be issued by the same issuer at the same date and same maturity date, in the same currency, as well as having all other bond characteristics identical. However, this is a rare scenario, and the sample would not be sufficient using these criteria. Instead, we allow for some margins within some of the matching criteria, where others have to be identical, such that we find a conventional bond to be as similar bond as possible to each green bond.

We match on the following criteria, where the first seven need to be identical. 1) The issuer, 2) currency, 3) credit rating, 4) coupon type, 5) maturity type, 6) seniority, and 7) collateral. This allows us to ignore variables that do not differ between green and conventional bonds. Further, 8) the amount issued cannot deviate by more than 400%, 9) coupon rate cannot deviate by more than 1%, 10) and date issued and maturity can deviate by no more than 5 years. This method is known as a model-free approach or a direct approach (Zerbib, 2019). It is similar to the limitations set as matching criteria by Bachelet et al. (2019) and Zerbib (2019), besides some adjustments where the margins have been extended to get a sufficient sample size. For each green bond we find a conventional bond to pair it with based on these limitations. Additionally, it is not possible to exactly match the liquidity of the separate bonds. A liquidity proxy is therefore included as a control variable, to increase the reliability of the results. This is further explained in the next section.

These restrictions leave us with 58 pairs in the Nordic bond market, and 119 pairs in the US bond market. A further explanation of the full sample is reviewed in section 4.4.

Table 1: Matching criteria for green and conventional bond matching

Matching method between green and conventional bonds

Bond Characteristics	Matching Criterion
Issuer	Same
Currency	Same
Credit rating	Same
Coupon type	Same
Maturity type	Same
Seniority	Same
Collateral	Same
Amount issued	+-400%
Coupon rate	+/-1%
Issue and maturity date	+/-5 years

Table 1 *shows the matching criteria used to match green and conventional bonds.*

3.3 Liquidity proxy

A potential weakness of the analysis can be that green and conventional bonds experience differences in liquidity. The residual differences in liquidity between the two asset classes and regions are not captured in the matching process. These differences can impact the relative pricing of green and conventional bonds. Therefore, by including a liquidity proxy, we can control for these residual differences. It is a measure of how quick and efficient a bond can be converted into cash at a fair market price (Financial Industry Regulatory Authority, 2022).

Numerous studies have applied the use of liquidity proxies, and there exist multiple measures of liquidity (Bao et al. 2011; Dick-Nielsen et al. 2011; Friewald et al., 2012; Sarig and Warga 1989). We use the difference in bid-ask spread between the green and conventional bonds as our proxy. Bid and ask prices might react differently when news arrive, but the bid and ask average should fluctuate randomly in an efficient market (Roll, 1984). Several previous studies investigating green and conventional bonds have used the bid-ask spread, such as Bachelet et al. (2019) and Zerbib (2019). We estimated the bid-ask spread using the standard formula:

Equation 2: *Bid-ask spread (Petitt et al., 2015).*

$$Bid - Ask\ spread = Ask\ price - Bid\ price$$

Liquidity risk refers to the risk that an investor may not be able to buy or sell a bond quickly and at a fair price due to a lack of market participants or trading activity (Petitt et al., 2015). Green bonds could be less liquid because there is less supply of these bonds compared to demand. If green bonds are less liquid than their conventional counterparts, any observed price differences could be due to differences in liquidity rather than the bond's green status. Therefore, not controlling for liquidity could lead to biased results.

3.4 Data description

The full sample consists of 354 bonds, where 177 are green and 177 are conventional. It consists of 58 matches in the Nordic market, and 119 matches in the US market. This corresponds to 2 674 observations of bond prices for the Nordic market, and 5 636 observations of bond prices for the US market. A few of the conventional bonds are used multiple times to match a green bond, as choosing the most similar conventional bond gives the most reliable results.

3.4.1 Data description Nordic

There are a total of 173 green bonds listed in the Nordic region within our research period from January 2017 to April 2023. Before starting the matching process there were 67 unique green bond issuers in the Nordics, however, after matching the bonds on the specified criteria the number of issuers declined to 35. There are 56 unique conventional bonds matched with these green bonds, meaning there are only two cases where a conventional bond is used multiple times to match a green bond.

The beneath overview gives a good impression of our full sample for the Nordic region. The reliability of the matching method is strengthened, as the margins that were allowed to differ in the matching method are relatively narrow between the green and conventional bond sample. Some statistics worth noting is that the currency dominating the sample is Euro, with 42 of the matched pairs being issued in Euros. Further, 57 of the matched pairs are rated investment-grade, which implies a relatively safe investment territory in terms of credit risk. The countries at risk are distributed among all the Nordic countries except Denmark, as no matches are found here. The majority part of issuers in the Nordics operate in the banking and industrial sector.

Table 2: Data description for the Nordic sample

Panel A: Sample Construction Nordics

	Bonds	Issuers
Full Green Bond Sample (Bloomberg)	173	67
Total Matched Green Bonds	58	35
Unique Conventional Bonds	56	35

Panel B: Full Sample Description Nordics

	Variable	Matched GB	% of total	Matched CB	% of total	CB - GB
Issue	Unique Issuers	35		35		
	Issue Date (mean)	14.02.2021		13.04.2020		
Maturity	Maturity Date (mean)	20.03.2027		04.06.2026		
	Maturity length (mean years)	6.09		6.14		-0.16
Currency	EUR	42	72.41%	42	72.41%	
	NOK	1	1.72%	1	1.72%	
	SEK	14	24.14%	14	24.14%	
	USD	1	1.72%	1	1.72%	
Credit Rating	Investment Grade	57	98.28%	57	98.28%	
	High Yield	1	1.72%	1	1.72%	
Amount Issued	Issue Amount (Total USD MM)	$ 34 089		$ 36 653		
	Issue Amount (Mean USD MM)	$ 588		$ 632		5.88***
Seniority	Senior Debt	58		58		
Collateral	Company Guarantee	5	8.62%	5	8.62%	
	Covered	19	32.76%	19	32.76%	
	Senior Secured	1	1.72%	1	1.72%	
	Senior Unsecured	33	56.90%	33	56.90%	
Coupon Type	Fixed	58		58		
Coupon	Coupon Rate (mean)	1.26%		1.31%		0.01**
Duration	Duration (mean)	3.49		2.75		-0.91***
Maturity Type	At Maturity	51	87.93%	51	87.93%	
	Callable	7	12.07%	7	12.07%	
Country of Risk	Finland	12	20.69%	12	20.69%	
	Iceland	3	5.17%	3	5.17%	
	Norway	15	25.86%	15	25.86%	
	Sweden	28	48.28%	28	48.28%	
Issuer Industry	Bank	33	56.90%	33	56.90%	
	Financial	7	12.07%	7	12.07%	
	Industrial	13	22.41%	13	22.41%	
	Special Purpose	4	6.90%	4	6.90%	
	Utility - Elec	1	1.72%	1	1.72%	
Total Number of Bonds		58		58		

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

***Table 2** describes the data for the Nordic bond sample. Panel A shows the amount of listed green bonds in the Nordic region, and how many of these that have been included in our sample. Panel B present the characteristics of the bonds included in our sample. T-tests for differences in means are shown in the right column.*

3.4.2 Data Description US

For the US market, there are a total of 251 green bonds issued within our research period, with 112 unique issuers. After applying the matching methodology, this number reduces to 119 green bonds and 72 unique issuers. There are 115 unique conventional bonds matched with green bonds, meaning that in four cases a conventional bond is used multiple times to match with a green bond, as it was the most similar.

Similar to the Nordic region, the US sample has close values for the matching criteria that are allowed to vary, indicating a thorough and precise matching process. USD is the currency dominating the market, and 115 of the matched pairs are rated investment-grade. 112 of the pairs are callable, meaning that it can be redeemed or paid off by the issuer before the bonds' maturity date. The issuer industries dominating the US market are financial, industrial, and the utility sector, which differ from the Nordic region where the banking industry dominates.

Table 3: Data description for the US sample

Panel A: Sample Construction US

	Bonds	Issuers
Full Green Bond Sample (Bloomberg)	253	112
Total Matched Green Bonds	119	72
Unique Conventional Bonds	115	72

Panel B: Full Sample Description US

	Variable	Matched GB	% of total	Matched CB	% of total	CB - GB
Issue	Unique Issuers	72		72		
	Issue Date (mean)	08.03.2020		25.04.2020		
Maturity	Maturity Date (mean)	03.07.2034		10.02.2034		
	Maturity length (mean years)	13.67		13.80		-0.63***
Currency	CAD	3	2.52%	3	2.52%	
	EUR	14	11.76%	14	11.76%	
	GBP	2	1.68%	2	1.68%	
	JPY	2	1.68%	2	1.68%	
	USD	98	82.35%	98	82.35%	
Credit Rating	Investment Grade	115	96.64%	115	96.64%	
	High Yield	4	3.36%	4	3.36%	
Amount Issued	Issue Amount (Total USD MM)	$ 74 271		$ 80 472		
	Issue Amount (Mean USD MM)	$ 628		$ 672		7,87***
Seniority	Senior Debt	119		119		
Collateral	1st Mortgage	16	13.45%	16	13.45%	
	Company Guarantee	29	24.37%	29	24.37%	
	General Ref Mortgage	3	2.52%	3	2.52%	
	Secured	2	1.68%	2	1.68%	
	Senior Secured	4	3.36%	4	3.36%	
	Senior Unsecured	64	53.78%	64	53.78%	
	Unsecured	1	0.84%	1	0.84%	
Coupon Type	Fixed	119		119		
Coupon	Coupon Rate (mean)	2,77 %		2,91 %		0,16***
Duration	Duration (mean)	8.03		7.59		-0,40***
Maturity Type	At Maturity	6	5.04%	6	5.04%	
	Callable	112	94.12%	112	94.12%	
	Sinkable	1	0.84%	1	0.84%	
Country of Risk	US	119		119		
Issuer Industry	Bank	1	0.84%	1	0.84%	
	Financial	44	36.97%	44	36.97%	
	Industrial	26	21.85%	26	21.85%	
	Special Purpose	4	3.36%	4	3.36%	
	Telephone	4	3.36%	4	3.36%	
	Trans - Rail	2	1.68%	2	1.68%	
	Utility - Elec	38	31.93%	38	31.93%	
Total Number of Bonds		119		119		

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

***Table 3** describes the data for the US bond sample. Panel A shows the amount of listed green bonds in the Nordic region, and how many of these that have been included in our sample. Panel B present the characteristics of the bonds included in our sample. T-tests for differences in means are shown in the right column.*

We include T-tests to test for differences in means between the green and conventional bond samples when possible. There will naturally be statistical differences in means between the two samples as we allowed some margins within some of the bond-specific characteristics. The column to the right (CB – GB) shows the differences in means between the samples, and whether they are statistically significant. This test improves the understanding of the samples and helps identify any significant differences that can have an impact on the result. Any statistical differences in means can be the root where issues in the outcome originate from.

3.5 Descriptive statistics

The tables below present the descriptive statistics for green and conventional bonds, both for the Nordic countries and for the US. Most of the characteristics are similar for the green and conventional bond samples in both regions, which indicates an accurate matching process. However, there are some notable differences between the green and conventional bond samples, in addition to some region-specific differences.

3.5.1 Descriptive statistics for the Nordic and US bond markets

The mean issue amount for Nordic green and conventional bonds are 588 million and 632 million, respectively. The median issue amount is 569 million for green bonds and 582 million for conventional bonds. This implies that the sample is skewed towards higher amounts issued, as the mean is considerably above the median value. In general, issuers of conventional bonds issue higher amounts, however, this may simply be down to the conventional bond market being more established and developed. In addition, green bonds have to follow strict regulations, which can reduce number of green bond issuers and subsequently their issue size (European Parliament, 2022). We see the same relationship for the US bond sample, where conventional bonds generally have higher amounts issued, at 628 million for green bonds and 672 million for conventional bonds. Also, the median values are lower which implies that there are more bonds with higher amounts issued that increase the average.

The first green and conventional match in our sample was found in March 2017, in the US sample. The mean maturity length is similar for the two bond types in the US, at 13.7 and 13.8 for respectively green and conventional bonds. Mean issue date and maturity date differ with a few months, however, green bonds are both issued earlier and matures later than their conventional counterparts. For the Nordic sample, the first green bond is issued in January

2018, however, the conventional counterpart was issued in September 2016. The mean maturity length is 6.1 for both bond types in the Nordics. This is less than half of the maturity length of the US bonds. This represents significant differences between the two markets which potentially can indicate notable disparities in interest rate risks.

In the Nordics, green bonds generally have lower mean and median fixed coupon rate than their conventional counterpart, with respectively 1.26% and 1.31% fixed coupons. The same goes for the American sample, where the fixed coupons on green bonds have an average of 2.77%, while the conventional bonds have an average of 2.91%. This implies that investors get higher compensation for investing in conventional bonds, holding the same risk, as credit risk within the matches had to be similar in the matching process. This is consistent with other studies' findings of investors that are willing to forego financial reward for sustainability reasons. The fixed coupons are generally lower in the Nordic sample, which can be down to lower perceived risk, lower duration, or higher credit ratings amongst the issuers in the sample. Other reasons can be down to monetary policies, inflation expectations and market demand. Since the US had more aggressive and frequent interest rate raises in the aftermath of the pandemic, the fixed coupons on bonds issued in this period would naturally be higher. Additionally, both supply and demand for green assets have a stronger position in the Nordic countries. Issuers face more competition as the relative share of new bonds issued in the Nordic countries are higher than in the US, and when demand is sufficiently matched as well, this pushes coupon rates down.

The bid-ask spread, which is a measure of liquidity, is almost similar between the two bond samples. It is 0.58 for the green bond market, and 0.62 for the conventional bond market. This shows that the liquidity within the green and conventional bond markets in the US, based on our sample, is similar. This means that it is almost equivalent level of difficulty when buying and selling bonds at a fair market price. The Nordic market has a wider bid-ask spread at respectively 0.35 and 0.28 for the green and conventional bonds. The narrower the bid-ask spread is, the more liquid the bond market is considered.

Finally, tests for differences in means show that all the tested variables have statistically significant differences in means between the two samples. This is expected as the bond prices, coupon, duration, amount issued, and bid-ask spread does vary between the two samples. The size of the effect is mostly minor, however, these differences may have an impact on the outcome and should not be ignored.

Table 4: Descriptive statistics for the Nordic sample

Panel A: Bond Characteristics (Nordic matched green sample)

	Mean	Median	SD	Min	25th Perc.	75th Perc.	Max	N	CB-GB (mean)
Mid price	95.30	97.85	7.25	69.34	90.14	100.90	109.85	1337	1.97***
Bid price	95.13	97.67	7.30	68.89	89.89	100.78	109.60	1337	2.00***
Ask price	95.48	98.06	7.21	69.78	90.38	101.04	110.11	1337	1.93***
Liquidity	-0.01	0,00	0.14	-0.46	-0.14	0,00	0.32	1337	
Coupon	1.26	0.75	1.35	0.01	0.37	1.72	4.84	1337	0.01**
Duration	3.49	3.21	1.76	0.01	1.93	4.14	7.70	1337	-0.91***
Amount issued (in MM)	588	569	397	30	332	806	1822	1337	5.88***
Maturity length	6.08	5.75	1.92	2.00	5.00	7.00	10.49	1337	
Maturity date	20.03.2027	28.12.2026	676.57	25.05.2023	25.02.2026	03.03.2028	16.06.2031	1337	
Issue date	14.02.2021	22.03.2021	489.69	30.01.2018	23.12.2019	09.02.2022	04.04.2023	1337	
Bid-ask spread	0.35	0.28	0.24	0.0111	0.18	0.49	2.39	1337	-0.01***

Panel B: Bond Characteristics (Nordic matched conventional sample)

	Mean	Median	SD	Min	25th Perc.	75th Perc.	Max	N	CB-GB (mean)
Mid price	97.27	99.18	6.04	72.84	94.33	101.36	108.41	1337	1.97***
Bid price	97.13	99.11	6.06	72.56	94.18	101.24	108.20	1337	2.00***
Ask price	97.41	99.27	6.01	73.13	94.48	101.48	108.62	1337	1.93***
Liquidity	-0.01	0,00	0.14	-0.46	-0.14	0.00	0.32	1337	
Coupon	1.31	0.75	1.36	0.01	0.37	1.75	4.57	1337	0.01**
Duration	2.75	1.61	1.98	0.00	0.98	3.59	8.40	1337	-0.91***
Amount issued (in MM)	632	582	419	51	274	1047	1722	1337	5.88***
Maturity length	6.14	7.00	2.32	2.00	5.00	7.00	15.00	1337	
Maturity date	04.06.2026	08.12.2025	891.31	30.05.2023	18.06.2024	26.01.2028	31.08.2033	1337	
Issue date	13.04.2020	20.05.2020	670.44	08.09.2016	29.08.2018	02.09.2021	20.02.2023	1337	
Bid-ask spread	0.28	0.22	0.21	0.04	0.14	0.36	1.69	1337	-0.01***

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

Table 5: Descriptive statistics for the US sample

Panel A: Bond Characteristics (US matched green sample)

	Mean	Median	SD	Min	25th Perc.	75th Perc.	Max	N	CB-GB (mean)
Mid price	94.04	95.45	12.33	55.48	84.77	101.29	132.03	2818	1.44***
Bid price	93.75	95.20	12.27	55.18	84.52	101.03	130.76	2818	1.42***
Ask price	94.33	95.68	12.40	55.78	84.99	101.55	133.29	2818	1.46***
Liquidity	-0.04	-0.01	0.59	-2.34	-0.15	0.11	18.04	2818	
Coupon	2.77	2.87	1.28	0.00	1.90	3.88	5.60	2818	0.16***
Duration	8.03	6.94	4.66	1.33	4.81	9.80	16.99	2818	-0.40***
Amount issued (in MM)	628	550	318	6	400	769	2000	2818	7.87***
Maturity length	13.67	10.00	8.91	3.00	4.98	30.47	40.00	2818	
Maturity date	03.07.2034	30.10.2030	3328.58	08.06.2023	15.06.2028	06.02.2035	15.06.2061	2818	
Issue date	08.03.2020	31.03.2020	498.85	03.03.2017	18.06.2019	23.03.2021	30.03.2023	2818	
Bid-ask spread	0.58	0.43	0.57	0.01	0.30	0.71	19.41	2818	0.04***

Panel B: Bond Characteristics (US matched conventional sample)

	Mean	Median	SD	Min	25th Perc.	75th Perc.	Max	N	CB-GB (mean)
Mid price	95.33	96.61	12.20	63.13	86.13	103.40	132.11	2818	1.44***
Bid price	95.01	96.29	12.16	62.79	85.79	103.19	131.31	2818	1.42***
Ask price	95.64	96.86	12.25	63.47	86.42	103.64	132.91	2818	1.46***
Liquidity	-0.04	-0.01	0.59	-2.34	-0.15	0.11	18.04	2818	
Coupon	2.91	3.05	1.24	0.25	1.95	3.90	6.13	2818	0.16***
Duration	7.59	6.57	4.51	0.00	4.22	8.52	16.85	2818	-0.40***
Amount issued (in MM)	672	544	514	6	400	849	4000	2818	7.87***
Maturity length	13.80	10.08	8.82	3.00	10.00	12.08	40.00	2818	
Maturity date	10.02.2034	15.01.2031	3146.30	08.06.2023	15.03.2029	15.02.2033	15.11.2059	2818	
Issue date	25.04.2020	12.05.2020	560.64	03.03.2017	24.06.2019	28.07.2021	30.03.2023	2818	
Bid-ask spread	0.62	0.47	0.47	0.02	0.31	0.82	27426,00	2818	0.04***

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

Table 4 and 5 *present the descriptive statistics for the Nordic and US bond samples. Panel A shows the bond characteristics for the green bond sample, while Panel B shows the similar characteristics for the conventional bond sample. Note: the "CB-GB (mean)" column test for differences in means between the two samples. Panels A and B show the same t-statistic for the green and conventional sample.*

4. Empirical methodology

This section aims to present and describe the empirical methodology we use in the analysis. Our dataset consists of an unbalanced panel data from the Nordic and US bond markets. We present the regression models applied to capture the differential effect interest rates have on the pricing of green and conventional bonds. We also apply various robustness tests to increase the credibility and reliability of our choice of model. Furthermore, to improve the understanding of how bond prices respond to interest rate change, we implement a DiD with two separate shocks. This approach allows us to study the pricing dynamics in periods of both decreasing and increasing interest rates.

4.1 Variable description

4.1.1 Dependent variable

We use mid-price as the dependent variable in the analysis, as it provides the most accurate measure of the true market value as it eliminates the bid-ask spread's skewness (Capital.com, 2018). The mid-price is the mean price of the bid and ask price of the bonds, which can be interpreted as the price that would be agreed upon if buyers and sellers had equal bargaining power. The mid-price also helps in mitigating the impact of adverse selection risk, which refers to the risk that one party in a transaction has superior information than the opposing party.

4.1.2 Explanatory variable and controls

Interest rates serve as the main explanatory variable, however, we include several control variables to see the effect of other factors on the comparative pricing of green and conventional bonds. The explanatory variable is the primary variable of interest in the analysis, the one we believe has a specific impact on the outcome or dependent variable. A control variable differs from an explanatory variable in the sense that it is not necessarily the variable we are interested in studying, but we know they might affect the dependent variable to some degree. By including these in our model we can control for their impact such that we can isolate the true effect of the explanatory variable, or interest rates in this case. This helps avoid omitted variable bias and gives a more accurate estimate of the relationship between interest rates and bond prices. In this paper, green dummy, coupon, amount issued, TTM, and liquidity are controlled for in the regressions. Issuer, credit rating, currency, coupon type, maturity type, seniority, and collateral are already controlled for as they had to be equal in the matching methodology to be included in the sample. We also include an interaction term to estimate the differential effect interest rates have on green bond prices and their conventional counterparts. We construct the interaction term by multiplying the green dummy variable with the interest rate variable.

4.2 Methodology and model selection

Previous studies investigating green bonds and their performance relative to conventional bonds have used different statistical tests to decide on the most appropriate choice of model. This analysis uses panel data to capture the differential effect fluctuations in interest rates have on green bond pricing against conventional bond pricing. To capture this, the analysis run regressions with pooled OLS and time FE (year FE). The OLS model estimates the relationship between the dependent variable and the explanatory variables by minimizing the sum of the squares of the differences between the observed and predicted values of the dependent variable (Wooldridge, 2019). The FE model allows for the individual-specific effects to be correlated with the explanatory variables (Wooldridge, 2019).

4.2.1 Fixed effects vs. random effects

FE models are commonly used in unbalanced panel data regressions. Bachelet et al. (2019), Flammer (2021), and Zerbib (2019) all used FE in their respective studies. They had the bond-specific yield as the dependent variable and wanted to identify a "greenium" while controlling for multiple variables, such as green dummy, liquidity, maturity, currency, and industry. By including time FE, we can control for variables that are constant across bonds but vary over time (Torres-Reyna, n.d.). Random effects (RE) model is generally more efficient, as they have smaller standard errors, However, the assumption of RE models, that the individual-specific effects are uncorrelated with the independent variables, is a strong one and may not be reasonable in many contexts. If this assumption is violated, then the RE estimator may be biased. FE models differ from RE models as they do not require the unobserved time-invariant effect to be uncorrelated with the explanatory variable in all time periods (Wooldridge, 2019).

We conduct a Hausman test to check whether a FE estimation or RE estimation is preferred. The Hausman test compares the coefficients of the FE and RE models to test the null hypothesis that they are systematically the same. The result of the Hausman test imply that we should reject the null hypothesis at any reasonable significance level (p-value<0.0001)[9]. This suggests that the bond-specific effects are correlated with some of the other explanatory variables in the model, indicating that the FE model is more appropriate.

4.2.2 Robustness tests and tests for individual effects

To further test whether FE are preferred over pooled OLS and RE, we conduct several robustness tests. These tests for individual effects, serial correlation, and multicollinearity and helps to improve the robustness of our choice of model. We apply an F-Test, Wooldridge Test, and Variance Inflation Factor (VIF) test.

First, the F-test is used to decide between a pooled OLS and a FE model. The null hypothesis is that there are no individual effects, or the pooled OLS model is sufficient. If the F-statistic is large, and thus the associated p-value is small, then the null hypothesis is rejected, and the FE model is preferred. However, the F-test assumes that individual effects are not correlated with the explanatory variables, and it assumes homoskedasticity and zero autocorrelation (Goldstein, n.d.). We get a p-value of 0.0000, thus the FE model is preferred over the pooled OLS, and there exists individual effects in the sample.

The Wooldridge test is used to check for serial correlation in panel data. If the result yields a significant test statistic, this indicates that the errors in the regression model are autocorrelated. This test is specifically constructed for panel data, and accounts for the structure of the data, meaning that it considers that our data is unbalanced. However, this test assumes no cross-sectional correlation (Drukker, 2003). The Wooldridge test has a p-value of 0.0000, indicating evidence of autocorrelation within the errors in our regression model.

Table 6: Robustness tests for the Nordic sample

	F-test	Wooldridge test	Hausman test
P-value	0.0000	0.0000	0.0000
Conclusion	Significant effect	Significant effect	FE > RE
Type	Individual effects	Serial correlation	FE vs RE

[9] Hausman test results are illustrated in Table 6 and 7.

Table 6 *presents the outcome of our tests for individual effects and serial correlation. It also includes the result from the Hausman test which evaluates the suitability of employing a fixed effects model versus a random effects model for the Nordic sample.*

Table 7: Robustness tests for the US sample

	F-test	Wooldridge test	Hausman test
P-value	0.0000	0.0000	Not applicable
Conclusion	Significant effect	Significant effect	-
Type	Individual effects	Serial correlation	FE vs RE

Table 7 *presents the outcome of our tests for individual effects and serial correlation. It also includes the result from the Hausman test which evaluates the suitability of employing a random effects model versus a fixed effects model for the US sample.*

The VIF test is applied to test for the presence of multicollinearity in the regression analysis. Multicollinearity occurs when the explanatory variables in a regression model are highly correlated, which can potentially bias the results and make them unreliable (Wooldridge, 2019). Wooldridge (2019) states a rule of thumb that a VIF value over 10 indicates a multicollinearity problem in the regression. However, it's important to note that the VIF test is not appropriate for time FE regressions, and thus is only applied to the pooled OLS models in our study. The average VIF value for the entire sample was a moderate 3.21. When dividing the sample into Nordic and US subsets, we found an average VIF value of 1.51 for the Nordic sample and 6.83 for the US sample. Duration and TTM obtained a VIF score of over 20 in the US sample. This is not unexpected as the TTM are one of the components in the duration equation. This is addressed later in the regression analysis of the US sample. Apart from this, our analysis provided relatively low VIF values, indicating that multicollinearity is unlikely to serve as a problem in the regressions applied in this paper.

Table 8: VIF tests

Test		Full Sample	Nordic	US
VIF	Interaction term	2.85	2.49	3.11
	Interest rate	2.14	2.07	2.17
	Green dummy	1.87	1.56	2.11
	Coupon	1.46	1.24	1.35
	Time-To-Maturity	7.78	1.16	22.65
	LN amount issued	1.01	1.28	1.02
	Duration	7.55	1.16	21.17
	Liquidity proxy	1.01	1.10	1.02
	Average VIF value	3.21	1.51	6.83

***Table 8** shows the results from the VIF test for the different samples.*

4.2.3 Difference-in-differences

We also implement a DiD regression to check for differences in bond pricing between green and conventional bonds, before and after an event. The DiD method includes a treatment group, green bonds, and a control group, conventional bonds. The DiD approach is based on the parallel trend assumption, meaning that in the absence of a treatment, the two groups should follow the same pattern (Angrist & Pischke, 2015). Cicchiello et al. (2022) applied a similar method when researching credit spreads in the European green bond market during Covid.

During our research period, from 2017 to 2023, there have been two major events that have impacted global financial markets, namely the Covid-19 pandemic and the invasion of Ukraine. These two events are included as shocks in the DiD analysis. We narrow the Covid-19 period to March 2020 to capture the immediate impact on bond prices as the pandemic hit the world and interest rates dropped. The timeframe for the shock induced by the invasion of Ukraine extends from March 2022 to April 2023. These two events mark periods with substantial shifts in interest rates, a key element in our research question. When Covid hit, interest rates were immediately sat down as a measure to stabilize the economy. In 2022, economic conditions started to improve, and governments began to raise interest rates. In this DiD analysis we aim to identify the impact of these two events on green and conventional bond pricing, analyzing if there exist any differential effect between the two asset types.

In our study, the essence of a bond's green status does not change over time, presenting a deviation from the typical DiD theory where the treatment status can vary (Schwerdt & Woessmann, 2020). Specifically, a bond is categorized as either green or conventional from it is issued to maturity and is not subject to any change in this status throughout its lifetime. Therefore, instead of treating the green status as the treatment variable itself, we view it as a characteristic that might interact differently with an external shock or treatment. In this context, the treatment is Covid and the Ukraine invasion, and the green or conventional status is an attribute to the bond which might result in different effects to a shock. The point of interest is therefore related to if the market shocks have a differential effect on green (treatment group) and conventional bonds (control group). Following this, the parallel trend assumption implies that in the absence of these market shocks, the green and conventional bond prices would follow the same trend over time, after controlling for other bond characteristics.

4.3 Model specifications

We have estimated several regression models, using pooled OLS and time FE. This is similar estimation methods as previous studies have applied (Bachelet et al., 2019; Flammer, 2021, Zerbib, 2019).

Equation 3: Pooled OLS and time fixed effects model specification

$$\begin{aligned} Mid\ price_{it} = \beta_0 + \beta_1 Green_i \times Interest\ rate_t + \beta_2 Interest\ rate_t + \beta_3 Green_i \\ + \beta_4 Coupon_i + \beta_5 TTM_{it} + +\beta_6 LN\ Amount\ issued_i + \beta_7 Duration_{it} \\ + \beta_8 Liquidity\ proxy_{it} + \beta_9 \gamma_t + \epsilon_{it} \end{aligned}$$

We estimate a pooled OLS regression model to check whether interest rate changes have a differential effect on the pricing of green and conventional bonds. The dependent variable is defined as change in mid-price for a bond. β_0 represents the constant term, or intercept, and represents the predictive mid-price if all independent variables were equal to zero. The variable $Green_i$ is a dummy variable that equals 1 if bond i is classified as green and 0 otherwise. The explanatory variables include an interaction term which is constructed by multiplying the interest rate variable and the green dummy variable. This is created to observe if there exist any differential effect on the pricing of green and conventional bonds when interest rates change. Coupon, TTM, the natural logarithmic (LN) of the amount issued, duration, and a liquidity proxy are also included as explanatory variables. Each β represents the change in mid-price corresponding to a one unit change in the respective independent variable. The subscript i indicate variables that change between bonds, whereas the subscript t indicate variables that change over time. The green dummy, coupon, and LN amount issued are time-constant for each bond, denoted by i. Interest rates change over time but is not bond specific, denoted by t. Finally, the interaction term, TTM, duration and liquidity proxy are both time-varying and specific to each cross-sectional bond denoted by it. The model estimates these relationships while allowing for individual-specific error terms, represented by the error term $\in_{it}$. The pooled OLS and time FE model specifications are similar except that the FE model includes a unique feature, time FE. The γ_t term represent this time FE term, and accounts for time-specific effects that influence mid-price but do not vary across bonds (Wooldridge, 2019).

We also estimate a DiD model, where the specification is somewhat different from the pooled OLS and time FE models. A similar approach is used by Cicchiello et al. (2022) when analyzing credit spreads during Covid.

Equation 4: DiD model specification

$$\begin{aligned} Mid\ price_{it} = {} & \beta_0 + \beta_1 Green_i \times Covid_t + \beta_2 Covid_t + \beta_3 Interest\ rate_t + \beta_4 Green_i \\ & + \beta_5 Coupon_i + \beta_6 TTM_{it} + \beta_7 LN\ Amount\ issued_i + \beta_8 Duration_{it} \\ & + \beta_9 Liquidity\ proxy_{it} + \beta_{10}\gamma_i + \beta_{11}\mu_i + \in_{it} \end{aligned}$$

This specification is similar to the pooled OLS, however, the interaction term is constructed by multiplying $Green_i$ and $Covid_t$. Additionally, a Covid variable is included which represents the specified period we have set. This coefficient shows the change in mid price that happened during Covid for bonds in general, whereas the interaction term captures the differential effect on the pricing of green and conventional bonds. The γ_i term represent the country FE, and the μ_i term represent industry FE, both controlled for in a selection of the DiD regressions. Country FE is only relevant for the full sample and the Nordic region, as the US sample only consist of one country. The other terms are similar to the specification for the pooled OLS regressions. The specification for the Ukraine invasion looks similar, besides the interaction term that is constructed by multiplying $Green_i$ and $Ukraine_t$. Further, the Covid variable changes to the period we sat as the Ukraine invasion.

4.3.1 Regression models

Models 1 and 2 adopt the pooled OLS regression approach. The mid-price serves as the dependent variable, with the interest rate serving as the explanatory variable. We include green dummy and the interaction term as control variables. The interaction term is crucial in these models, as it is designed to capture the differential effect interest rates have on the pricing of green and conventional bonds.

Model 2 is similar to Model 1, besides having additional control variables. We include coupon, TTM, amount issued, duration and a liquidity proxy to the model to control for potential differences in pricing that is down to bond-specific characteristics or differences in liquidity. To account for scale differences and enhance interpretability we use the natural logarithm transformation for the amount issued variable. This creates a "LN amount issued" variable.

All four models include clustered standard errors, related to the variable "Pair_id". This variable is an identification variable for each of the pairs of green and conventional bonds, where each match has its own pair number. This adjustment specifies that the standard errors allow for intragroup correlation, meaning correlation within groups of observations defined by the "Pair_id". In other words, the observations within each group are not assumed to be independent (Stata, n.d.). These standard errors better reflect the uncertainty in the sample and increase the robustness (Wooldridge, 2019). Oppositely, ordinary standard errors assume that each observation is independent from all others, and that the error term is homoscedastic (Wooldridge, 2019).

Previous studies have used similar approaches. Bachelet et al. (2019), Flammer (2021), and Zerbib (2019) used pooled OLS estimation in their respective studies on green bonds. In addition, they apply FE regressions to their studies to capture differential effects that is down to the choice of model.

We design Model 3 and Model 4 as pooled OLS regressions with time FE. We apply this approach to control for factors that vary over time but not across bonds. One of the key benefits of applying this approach compared to running entity FE is that it prevents the time-invariant variables such as the green dummy variable, coupon, and amount issued to be omitted. By adding time FE, we are able to control for unobserved time trends that are constant across bonds, reduce omitted variable bias, and it adds flexibility to the model by enabling us to look at effects that is down to the separate years. A downside of adding time FE is that it could yield multicollinearity issues. If the year variable is highly correlated with any of the explanatory or control variables, including time FE could introduce multicollinearity issues, which can make the estimates less precise and harder to interpret.

5. Results

This section presents the results from the models introduced in the methodology section. The different models are evaluated and compared to see if they provide the same results. From this we are able to see whether the recent interest rate fluctuations have a differential effect on the pricing of green and conventional bonds, and if there exist any regional differences between the two markets. We want to see the total effect of interest rate changes on bond prices for the full sample, before splitting the two samples into the Nordic and US region.

5.1 Regressions

5.1.1 Regressions for the full sample

Model 1 in Table 9 show that when interest rates increase by one percent, bond prices decrease by 363 bps, which is consistent with previously discussed theory. This is significant at the 1% level. The green dummy coefficient implies that green bonds are on average priced 133 bps lower than their conventional counterparts, significant at the 1% level. However, the interaction term is not significant, but indicates that green bond prices decrease with an additional 14 bps compared to their conventional twins, when interest rate increase by one percent. The explanatory power, or R-squared, of this model implies that 35.4% of the variation in bond prices can be explained by the included variables.

Model 2 adds several control variables to see what effect bond-specific characteristics and liquidity have on the pricing of bonds when interest rates change. This model shows that when interest rates increase by one percent, bond prices decrease with 370 bps, and is significant at a 1% level. The green dummy variable changes substantially but is not significant. In this model, the interaction term implies that when interest rates go up by one percent, green bonds decrease by an additional 19 bps, and is significant at the 5% confidence level.

Several of the control variables are significant at 1% or 5% confidence level. The coupon variable indicates that a 1% increase in coupon rates are associated with a 324 bps increase in bond price. This is consistent with bond pricing theory, as higher coupon rates are associated with higher interest rate payments for bondholders, and subsequently higher bond prices. Further, the TTM variable implies that when time to maturity increase by one year, bond prices increase by on average 53 bps. Finally, a one unit increase in duration are associated with a

168 bps decrease in bond prices. If interest rates rise, bond prices fall, and this effect is more significant for bonds with longer duration. This is simply because bonds with longer duration have a longer stream of future payments. This could be discounted at the new, higher interest rate, leading to a decrease in bond price. In general, this model explains 53.8% of the total variation in bond price, indicating that the control variables play a significant role in the model.

Table 9: Regression results for the full sample

	Dependent variable:			
	Mid-Price			
	(1)	**(2)**	**(3)**	**(4)**
Variable				
Green × Interest rate	-0.144	-0.185**	-0.212***	-0.200***
	(0.092)	(0.083)	(0.078)	(0.077)
Interest rate	-3.631***	-3.730***	-3.354***	-3.346***
	(0.228)	(0.270)	(0.183)	(0.189)
Green	-1.334***	-0.131	-1.086***	-0.146
	(0.423)	(0.276)	(0.303)	(0.225)
Coupon		3.237***		3.556***
		(0.351)		(0.276)
Time-to-Maturity		0.530**		0.164***
		(0.233)		(0.046)
LN amount issued		0.664		0.444
		(0.568)		(0.406)
Duration		-1.682***		-1.161***
		(0.414)		(0.122)
Liquidity proxy		1.231		0.300
		(0.980)		(0.371)
Constant	101.831***	86.814***	99.284***	86.781***
	(0.685)	(11.519)	(0.726)	(8.249)
Year Fixed Effects	No	No	Yes	Yes
Observations	8218	8218	8218	8218
R-squared	0.354	0.538	0.5267	0.666
F-Statistic	127.90***	77.82***		
Wald Chi			278510.68***	30609.91***

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

***Table 9** presents the regression results for the whole sample across all four specifications*.

Model 3 and 4 in Table 9 includes time FE regressions to capture parts of the time-varying unobserved effects that are constant across entities (Torres-Reyna, n.d.). Model 3 provides a significant negative interaction term of 21 bps, which indicates that interest rates have a significant differential effect on the pricing of green and conventional bonds, affecting the bond price of green bonds more. Model 4 provides similar results where several explanatory variables are added to the regression. R-squared increases from 52.7% in Model 3 to 66.6% in Model 4, which indicates that the added control variables contribute to explain more of the change in bond prices. After adding the control variables, we can see a significant change in the green dummy variable, and it is no longer significant. Model 2 and Model 4 shows positive coefficients for coupon rate and TTM, and negative coefficient for duration, all significant at the 1% level.

The next regression models are divided into the Nordic and US bond markets. We present mainly the results from Model 4 for the next regressions, as the coefficients are somewhat similar. Furthermore, this model comprehensively includes all control variables, time FE, and offers the highest R-squared value among all models.

5.1.2 Regressions for the Nordic sample

Compared to the full sample, Table 10 shows that the relationship between the interaction term and bond price are greater and significant across all models, indicating that interest rates have a greater differential effect on the pricing of green bonds in the Nordics. Model 4 is indicating that a one percent increase in interest rates is associated with 147 bps decrease in bond price in general with an additional decrease of 93 bps for green bonds. These results are statistically significant at the 1% level. Adding this up, it implies that on average a one percent increase in interest rates cause a 240 bps decrease in the mid-price for the green bonds.

Even though traditional bond theory may not directly address the impact of issuance size on bond pricing, our findings imply a minor significant positive relationship between the amount issued and bond pricing. A one percent increase in the natural logarithm of the amount issued variable corresponds to an increase of 102 bps in the mid-price of the bonds. Coupon and TTM remains a positive relationship with the bond price across the models and are consistent with basic bond pricing theory.

Table 10: Regression results for the Nordic sample

	Dependent variable:			
	Mid-Price			
	(1)	(2)	(3)	(4)
Variable				
Green × Interest rate	-0.888***	-0.889***	-0.970***	-0.927***
	(0.209)	(0.232)	(0.210)	(0.215)
Interest rate	-1.772***	-1.779***	-1.655***	-1.469***
	(0.345)	(0.357)	(0.282)	(0.296)
Green	-1.083**	0.720*	-0.655	0.725**
	(0.490)	(0.390)	(0.424)	(0.390)
Coupon		1.889***		2.569***
		(0.347)		(0.230)
Time-to-Maturity		0.127**		0.143***
		(0.026)		(0.042)
LN amount issued		0.859**		1.016***
		(0.340)		(0.267)
Duration		-1.764***		-1.589***
		(0.163)		(0.135)
Liquidity proxy		4.545*		4.657
		(2.719)		(3.492)
Constant	99.035***	84.309***	98.471***	78.372***
	(0.574)	(6.822)	(0.532)	(5.447)
Year Fixed Effects	No	No	Yes	Yes
Observations	2674	2674	2674	2674
R-squared	0.251	0.507	0.440	0.655
F-Statistic	31.79***	45.30***		
Wald Chi			43383.62***	30609.91***

Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 10 *presents the regression results for the Nordic sample across all four specifications.*

5.1.3 Regression for the US sample

Compared to the Nordic market we find that interest rates have a significantly higher impact on the pricing of bonds in general in the American market presented in Table 11. A one percent increase in interest rates correspond to a decrease in mid-price of 347 bps. This constitutes to more than twice the effect interest rates have on bond prices in the Nordic market.

The green dummy variable suggests that green bonds on average are priced lower than the conventional bonds, however, this coefficient is not significant in Model 4. All coefficients for the interaction term are close to zero and is not significant. This suggest that interest rates have no differential effect on the pricing of green and conventional bonds in our US sample.

The impact of control variables on mid-prices demonstrates considerable similarity across the US and Nordic markets. Notably, the FE models suggest that a one percent increase in the coupon rate corresponds with a 425 bps increase in mid-price. This effect is significantly higher compared to the Nordic market. The duration variable is statistically significant at the 1% level, with a positive coefficient of 1.59. This indicates that a one unit increase in duration is associated with a 159 bps increase in bond price. This is opposite to what we find for the full sample and for the Nordic sample. Overall, this model holds an R-squared of 72.8%, meaning that a big portion of the variation in mid-price can be explained by the explanatory variables. Compared to other studies (Bachelet et al., 2019; Zerbib, 2019), our R-squared is considered to be high and provides confidence in the explanatory power of our chosen variables and validity of our chosen models.

The VIF test presented in Table 8 identifies a potential multicollinearity issue between the duration and TTM variables in the US sample. To control for this potential multicollinearity problem, we removed the duration variable from our regression analysis to check for any substantial deviations. As a result, the VIF score for TTM decreases to 1.20, a score considered favorable, indicating no significant evidence of multicollinearity. Interestingly, this exclusion did not affect our key variables of interest: the interaction term, interest rate, and green dummy variables. Their significance and interpretation remained consistent, reinforcing the robustness of our key findings. However, a significant shift was observed in the TTM variable. After the exclusion of duration, TTM switched from a positive 42 basis points to a negative 37 basis points, as well as the significance level shifted from the 10% level to the 1% level.

Table 11: Regression results for the US sample

	Dependent variable:			
	Mid-Price			
	(1)	**(2)**	**(3)**	**(4)**
Variable				
Green × Interest rate	0.021	-0.009	-0.034	-0.032
	(0.099)	(0.085)	(0.076)	(0.076)
Interest rate	-4.327***	-4.063***	-3.521***	-3.467***
	(0.250)	(0.252)	(0.161)	(0.167)
Green	-1.477**	-0.488	-1.302***	-0.282
	(0.608)	(0.371)	(0.401)	(0.270)
Coupon		3.289***		4.253***
		(0.498)		(0.414)
Time-to-Maturity		1.231***		0.420*
		(0.354)		(0.223)
LN amount issued		-0.009		-0.095
		(0.906)		(0.615)
Duration		-2.972***		1.594***
		(0.619)		(0.430)
Liquidity proxy		0.826		0.212
		(0.949)		(0.366)
Constant	103.672***	102.083***	100.110***	94.990***
	(0.985)	(18.506)	(0.877)	(12.552)
Year Fixed Effects	No	No	Yes	Yes
Observations	5544	5544	5544	5544
R-squared	0.396	0.598	0.585	0.728
F-Statistic	113.21***	63.750***		
Wald Chi			147759.56***	69662.62***

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 11 *presents the regression results for the US sample across all four specifications.*

5.1.4 Difference-in-differences regressions

Our DiD analysis presents the regressions for the full sample at first then proceed by dividing the regressions into the two separate regions Nordic and US, thereby highlighting any regional differences. Table 12 presents the DiD results for the Covid shock and Table 13 present the Ukraine shock. The first[10] regression in each of the samples include the specific period, the green dummy and the interaction term between the shock and the green dummy. The second[11] regression in each of the samples includes additional control variables, the same that we apply in the pooled OLS regressions. Further, we introduce both country FE and industry FE, which allows us to control for within-country and within-industry variation (Mason, 2001). We don't include time FE as we have constructed specific periods that would crash with any time FE, disturbing the results.

For the first regressions in Table 12 we identify the notably low R-squares suggesting limited explanatory power, potentially due to the brief timeframe constructed for the Covid shock. The second regression captures small positive coefficients for the interaction term and negative coefficients for the Covid variable, however, none of the results are statistically significant. The green dummy variable exhibits a negative relationship, implying that green bonds are priced lower than conventional bonds. Results are indicating a 41 bps lower price for green bonds in the full sample, significant at the 1% level, and a 47 bps lower for the US sample, significant at the 5% level. The Nordic sample does not present a statistically significant result for the key variables of interest. The interpretation of the explanatory variables aligns with those we obtain from the pooled OLS and time FE regressions.

For the Ukraine shock, the first regressions in each sample provide significantly higher R-squared which may be due to the longer timeframe of the shock. In the second regression for the full sample, the interaction term indicates that green bond prices decline by additionally 82 bps. The comparable number for the Nordic sample indicates a 256 bps additional decline in green bond prices, both statistically significant at the 1% level. The variable for the Ukraine shock suggests that bond prices in general dropped significantly higher in the US sample than in the Nordic sample (1 368 bps decrease against 576 bps decrease). This is consistent with the findings from the pooled OLS regressions. The full sample and the US sample maintain

[10] The first regressions in each sample are referring to regression 1, 3 and 5 in Table 12 and 13.

[11] The second regressions in each sample are referring to regression 2, 4 and 6 in Table 12 and 13.

statistically significant negative coefficients for the green dummy variable. However, contrary to results from Table 12, the green dummy variable for the Nordic sample indicates that green bonds are priced 83 bps higher than conventional bonds, significant at the 1% level. This aligns with the findings from Table 9, where the coefficient of the green dummy variable also switches from negative to positive with the inclusion of the explanatory variables.

Table 12: Difference-in-differences regression for Covid-period

	Dependent variable: Mid-Price					
	Full sample		**Nordic sample**		**US sample**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Variable						
Green × Covid	0.300	0.134	0.785	0.117	0.146	0.041
	(2.863)	(1.858)	(3.575)	(2.282)	(3.740)	(2.355)
Covid	7.917***	-0.484	3.367	-1.405	9.511***	-1.047
	(2.025)	(1.317)	(2.528)	(1.616)	(2.644)	(1.670)
Green	-1.566***	-0.406***	-1.970***	-0.215	-1.438***	-0.473**
	(0.241)	(0.157)	(0.259)	(0.172)	(2.495)	(0.211)
Interest rate		-4.156***		-3.062***		-4.141***
		(-0.050)		(0.071)		0.064
Coupon		3.593***		2.639***		3.281***
		(0.086)		(0.120)		(0.115)
Time-to-Maturity		0.386***		0.118***		1.135***
		(0.026)		(0.020)		(0.060)
LN Amount issued		0.354***		0.1.243***		-0.211
		(0.118)		(0.155)		(0.152)
Duration		-1.543***		-1.605***		-2.907***
		(0.049)		(0.049)		(0.113)
Liquidity proxy		1.266***		3.488***		0.943***
		(0.165)		(0.649)		(0.185)
Constant	95.967***	93.518***	97.525***	76.847***	95.411***	107.014***
	(0.170)	(2.387)	(0.183)	(3.104)	(0.236)	(3.100)
Country Fixed Effects	No	Yes	No	Yes	No	No
Industry Fixed Effects	No	Yes	No	Yes	No	Yes
Observations	8218	8218	2674	2674	5544	5544
R-squared	0.009	0.583	0.023	0.604	0.008	0.608
F-statistic	24.79	1240.37	20.85	418.27	15.01	931.73

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 12 *presents the results for the DiD regression with Covid-19 shock.*

Table 13: Difference-in-differences regression for Ukraine-period

	Dependent variable:					
	Mid-Price					
	Full sample		**Nordic sample**		**US sample**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Variable						
Green × Ukraine	-0.810***	-0.818***	-2.533***	-2.555***	0.019	0.028
	(0.335)	(0.264)	(0.359)	(0.264)	(0.442)	(0.345)
Ukraine	-15.236***	-10.607***	-8.268***	-5.758***	-18.593***	-13.677***
	(0.237)	(0.234)	(0.254)	(0.228)	(0.312)	(0.319)
Green	-1.136***	-0.158	-0.638***	0.827***	-1.447***	-0.538**
	(0.244)	(0.193)	(0.260)	(0.265)	(0.322)	(0.252)
Interest rate		-1.897***		-1.241***		-1.667***
		(-0.058)		(0.075)		0.071
Coupon		3.567***		2.689***		3.585***
		(0.073)		(0.075)		(0.095)
Time-to-Maturity		0.115***		0.030*		0.365***
		(0.022)		(0.017)		(0.052)
LN Amount issued		0.088		0.856***		-0.480***
		(0.100)		(0.124)		(0.125)
Duration		-1.010***		-1.305***		-1.457***
		(0.043)		(0.040)		(0.097)
Liquidity proxy		0.849***		2.759***		0.602***
		(0.139)		(0.520)		(0.152)
Constant	104.084***	100.307***	101.602***	85.339***	105.367***	112.475***
	(0.172)	(2.028)	(0.184)	(2.495)	(0.228)	(2.562)
Country Fixed Effects	No	Yes	No	Yes	No	No
Industry Fixed Effects	No	Yes	No	Yes	No	Yes
Observations	8218	8218	2674	2674	5544	5544
R-squared	0.518	0.702	0.528	0.747	0.563	0.734
F-statistic	2936.32	2091.45	596.06	820.87	2375.97	1662.99

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 13 *presents the results for the DiD regression with the Ukraine-invasion shock.*

6. Discussion

This section discusses and compare the findings of our analysis with relevant theory and existing literature on the topic. The second part discuss the limitations of this paper within the context of the evolving green bond market which aims to offer a balanced perspective on our research for additional exploration on this topic.

6.1 Discussion of results

The results from our regressions indicate that green bonds experience greater volatility than their conventional counterpart in the Nordic bond market. However, this result is not statistically significant in the American bond market. Based on our findings, the null hypothesis, that the green bond market is more resilient to interest rate changes, can be rejected for the Nordic bond market. This implies that there exist statistically significant differences in the pricing of green and conventional bonds, where we find green bonds to be more sensitive to interest rate changes.

For the American market, there is not sufficient evidence to reject the null hypothesis, however, this does not mean that the null hypothesis is true. The reason for this could be down to issues related to the sample, such as sample size, high variability in the data, or the effect size is too small to detect. Our results imply that green bonds in the US are slightly more impacted by a one percent increase in interest rate, with a negative coefficient of 3 bps, however, the interaction term that captures the differential effect of green bonds compared to conventional bonds is not significant. As the coefficient is relatively small compared to the similar coefficient in the Nordic market, this may imply that our model cannot capture the differential effect of green and conventional bond prices due to the effect size.

In the literature review, we highlight findings from ING (2023) and Deschryver and De Mariz (2020), which identified differences in investor behavior across the Nordic and US markets. Their findings suggest that there is a higher focus on sustainability and ESG investing within the Nordic region compared to the US. These differences support our expectations that there may exist regional differences and that interest rates have a smaller differential effect in the US bond market, compared to the Nordic bond market. However, it does not explain why Nordic green bonds are more sensitive than their conventional counterparts toward interest rate fluctuations. Here, the aspects of bond duration and interest rate risk become prominent.

This is consistent with Juvyns' (2023) paper which conducted a similar study and used similar matching criteria as this paper, with some expectations. He also observed greater volatility in the green bond market, attributing this primarily to the longer duration characteristic of the green bond sample. This is consistent with our findings, as we observed the green bond sample in both the Nordic and US markets to have greater durations than the conventional sample.

We also believe it is noteworthy to highlight that the green dummy coefficient in the Nordic regression in Table 10 transitions from negative to positive with the inclusion of the explanatory variables in Model 2 and 4. We notice that this shift is attributed to the introduction of the duration control variable. Model 4 indicates that, with all other things being held constant, green bonds are priced 73 basis points higher when controlling for all the independent variables. This shift is specific to the Nordic region and does not hold true for the US. This is in line with existing literature that finds there to be a generally higher focus on sustainable investing in the Nordics compared to the US.

This also aligns with prior research suggesting the presence of a "greenium". This might offer a plausible explanation for the shift in the green dummy coefficient from negative to positive when additional control variables are included. However, we want to emphasize that despite the statistical significance of this result, it does not validate a definitive conclusion, as the primary focus of our study lies in exploring the differential effect interest rates have on the pricing of green and conventional bonds.

Besides higher duration, there exist other reasons as to why green bonds experience greater sensitivity to interest rate changes in the Nordic market. These include both bond-specific and market-specific factors, though it is challenging to specify the significance of the individual factors. As it is a relatively new market, and less matured than the conventional bond market, it could lead to greater price volatility as market participants are not as experienced with these securities and still is learning about the risk and return characteristics of these bonds. The green bond market accounts for a relatively small fraction of the total bond market, which in turn may affect the liquidity of the market, making it harder to buy and sell bonds efficiently. Further, investor demand can be influenced by a variety of factors, including policy changes, news related to climate change, or other societal attitudes towards environmental issues (European Central Bank, 2007). Changes in these factors can change demand and subsequently lead to fluctuations in bond prices. Perceived risk among investors is another element impacting bond prices, where higher risk often is associated with higher price volatility (Fidelity International, 2023). However, as Krüger (2015) argue, green assets are perceived less risky by investors, indicating that the differences in pricing does not originate from this.

Our second hypothesis, we expected interest rates to have a weaker differential effect in the US bond market compared to the Nordic. This hypothesis can be accepted, as our findings indicate that green bonds in the Nordic region are more sensitive to interest rates changes. For the US market, we found that bonds generally have significantly higher sensitivity towards interest rate changes than in the Nordics, but that interest rates have no scientific differential effect on the pricing of green and conventional bonds.

We find it more difficult to identify the reason why green bonds are less volatile toward interest rate changes compared to conventional bonds in the US than in the Nordics, especially since it appears to be a bigger focus on sustainable investing in the Nordics than in the US. We know that sustainable bonds are more integrated into the debt capital market in the Nordics as 11% of all corporate bonds issued in 2021 were earmarked green while the comparable number for the US market was just 4%. The green bond sample in the US also showcases a higher duration than the conventional sample. However, the duration gap in percentage is significantly higher in the Nordic sample. This might be one explanation for why we find it easier to identify that interest rates have a differential effect on the pricing of the two asset classes in the Nordic sample than in the US sample. Another plausible explanation can be the longer maturity associated with the US bonds in our sample compared to the Nordic sample (13.7 years versus 6.1 years). It is acknowledged that green investments often require substantial upfront costs and can entail longer periods to profitability. This disparity in maturity can provide green bonds with a competitive edge in the US market.

The excessive volatility we see in the American bond market might be due to several aspects differentiating it from the Nordic bond market. First, the US government implemented more frequent and aggressive interest rate hikes, which is associated with more volatile financial markets, including bond prices. This is reflected in our results, where we find US bond prices to decrease more when interest rates increase. Furthermore, the bonds in our US sample both show significantly greater maturity and duration than the Nordic bond sample. This indicates that the bonds in the American sample are more exposed to interest rate changes, leading bond prices to vary more. This is consistent with the findings of Juvyns (2023) and CBI's (2022) report which found that bonds with greater duration are more volatile due to greater interest rate risk.

The coupon variable from the pooled OLS regressions[12] indicates that when coupon rates increase, bond prices go up, a consistent relationship seen in both regions. This is essentially consistent with theory, as higher coupon rates yield higher interest payments for bondholders, driving the price up. However, this relationship is more complex and can be influenced by other factors as well. The coupon rate must be seen in relation to prevailing interest rates, as they largely affect the coupon rates on newly issued bonds. If a newly issued bond with fixed coupon has a higher rate than comparable bonds in the market, it is more attractive to investors because it promises to pay more interest over the bond's lifetime. Additionally, TTM impacts the bond prices, as bonds that are closer to maturity are less sensitive to changes in interest rates. The TTM variable shows for all models that when TTM increases, bond prices go up. This is counterintuitive as bonds with longer maturity should have pricing benefits due to the increased risk of holding bonds with longer maturity.

The duration variable remains negative in the Nordic regressions in Table 10, however, in model 4 for the US regression it changes to a positive coefficient. When duration increases, it implies that the bond's price is more sensitive to changes in interest rates. This variable has to be interpreted in relation to the direction interest rates move. If interest rates increase, the price of a bond with a longer duration falls by a greater amount than the price of a bond with a shorter duration, and vice versa. This means that an increase in duration does not directly cause a bond's price to increase or decrease.

The liquidity proxy variable is only statistically significant at the 10% for Model 2 in the Nordic regression. In addition, the R-squared of the models experience nearly zero change when adding the liquidity proxy as a control variable. This indicates that the variable is not of high importance, as it explains little of the variation in mid-price.

As discussed earlier, demand for green assets have increased dramatically in recent years, however, the supply of green bonds does not always match sufficiently. Issuing green bonds requires stringent certification and regulatory processes which can be costly, deterring potential issuers. Additionally, the scale of eligible projects is somewhat limited. The projects

[12] Tables 9, 10 and 11

that can be financed using green bonds are often large-scale and capital intensive, limiting the number of eligible issuers. Lack of financial incentives and profitable green projects also limits the supply side of green bonds. The report by European Commission (2016) found that companies struggle to achieve similar credit ratings on their green bonds as they would on their conventional, increasing the cost of financing and complicating the process of issuing green bonds.

Our research period encompasses years with unforeseen events that had a global impact and increased uncertainty in debt capital markets. The Covid-19 pandemic forced governments to make considerable and rapid decreases in interest rates, which consequently had a significant impact on bond prices. In general, increased uncertainty in the financial markets will increase volatility in bond markets (Albulescu, 2021). Looking at the interest rate curve in Figure 4, the period after the Ukraine invasion in February 2022 until April 2023 is associated with a period of consistent increasing interest rates. This is one of the main reasons for seeing the substantial fall in bond prices during this time frame. The US implemented more aggressive and frequent interest rate hikes, which is reflected in the excessive decrease in bond prices seen in the American bond market. The DiD approach has some downsides, one of them being that it is not possible to point out the magnitude of the specific individual effects in the interaction term between the shock and the green dummy. This only shows the general effect on bond prices during the specified period, however, there could be several aspects influencing the magnitude of the coefficients.

6.2 Limitations

While our research was conducted thoroughly, several limitations regarding the matching method, data collection, model assumptions, and macroeconomic factors are observed. These are important to account for to enhance the understanding of this paper and promote future research on this topic.

A primary limitation in this paper is related to the matching process. The premise of this technique is based on the assumption that the pairs are similar in all aspects, except for their status as being green or not. However, achieving a sufficient sample size with perfect matches is challenging, hence some variation is allowed within some of the bond characteristics. These margins can introduce some bias into our analysis, as the prices of bonds with different maturities and coupons react differently to interest rate changes. In addition, some issuers exclusively issue green bonds, and thus no conventional counterpart where identified. This limits the data quality, as a substantial share of green bonds where lost due to this or not fulfilling the other matching criteria. The same goes for conventional bonds, as there were several conventional bonds for each green bond, but only one was included in the sample. Therefore, our sample might not be representative for the bond market as a whole.

Additionally, there are companies that exclusively issue conventional bonds, such as oil and gas, which is heavily weighted in the Nordic financial environment. This limits our findings as bonds related to oil and gas cannot be included in the sample as they do not achieve green financing. This implies that an important segment of the Nordic and US investment territory is omitted, meaning that the results should not be generalized to all industries. Moreover, selection bias could arise in the process of collecting data. For instance, in this paper, nearly all bonds are rated investment-grade bonds. This implies that the results cannot be generalized to the full bond market as this posits a greater diversity of bond ratings.

Further, it is important to notice that the bonds hold different bond-specific characteristics, and thus cannot be generalized to all types of bonds. In addition, as this paper investigates the Nordic and American bond markets, the result should only be applied to these specific markets. And since the Nordic sample is heavily weighted by Norwegian and Swedish bonds, and no Danish bonds are included in the sample, the results should be interpreted accordingly.

The chosen time frame for this paper, going from 2017 to April 2023, encompasses a unique and turbulent period in the global economy that could result in unnatural bond performance. Unforeseen events, such as the Covid-19 pandemic and the Ukraine war, have significantly impacted financial debt markets, including interest rates and bond prices. The results should be interpreted in the context of the economic environment that the study period encompasses. Most bonds in our sample are issued during or after the pandemic, which implies that the bond prices have traded in an economic environment with increased uncertainty and noise. In addition, the rapidly evolving nature of the green bond market could also complicate the applicability of the results, as the characteristics and market perceptions of green bonds might differ significantly from 2017 to 2023, as the focus on sustainable investments have increased.

Statistical model assumptions represent another limitation of this paper. The pooled OLS and FE models applied in this analysis take certain assumptions, including linearity, independence, homoscedasticity, and normality of errors, and violations of these assumptions might lead to spurious results. In addition, these models generally assume that all relevant explanatory variables are included in model. If important variables are omitted, or they are not included due to data constraint or being non-measurable, this could lead to omitted variable bias where the effect is erroneously attributed to the included variables, leading to spurious results. Therefore, the robustness of our findings relies on these model assumptions being tested and fulfilled.

For the DiD regression, our initial approach involved implementing a staggered DiD model to explore the differential impact of interest rate fluctuations on bond prices across various countries. This model could provide us with a better understanding on this relationship and might identify additional factors or circumstances that influence bond pricing. More specifically, it could help us investigate whether bond prices react differently in each country, even when their specific interest rates move in the same direction. However, we concluded that the results were excessively biased to be incorporated in this paper. Instead, we adopted a DiD model with two shocks, corresponding to periods of significant global interest rate changes. Future work could benefit from effectively implementing a staggered DiD model and acquiring more detailed results.

7. Conclusion

In the Nordic market, we find that green bond prices exhibit greater sensitivity to interest rate changes compared to conventional bonds. This suggests that the increasing demand for green assets does not necessarily translate into a more stable market in terms of interest rate fluctuations. Factors such as bond duration and TTM seem to have a stronger influence on the pricing, making the market for green assets more volatile. We identify this as a potential obstacle to green financing in the Nordic market, particularly when anticipating periods of higher interest rates.

Interestingly, this differential effect of interest rates on bond pricing was not observed in the American market. However, we find that bonds are generally more volatile in the US market than in the Nordics. We identify this to be mainly because of the significantly higher duration and TTM in the US sample. This may suggest that investors in the US are more comfortable with longer-term debt obligations. Further, we identify sustainability to be less integrated into the US debt capital markets. This, coupled with prevailing uncertainties around ESG investing, may account for the lack of observed differential impact. Furthermore, the relatively smaller duration gap between green and conventional bonds in the US compared to the Nordic suggests a weaker differential effect between interest rates and bond prices in the US.

The DiD results indicates that the American bond market generally experience greater volatility. During Covid, a significant negative effect is found after including all the control variables, suggesting that bond prices dropped. However, the greatest impact was seen in the aftermath of the Ukraine invasion, with US bond prices generally experiencing excessive volatility, mainly due to higher duration. Only for the Nordic sample an additional effect is found related to green bonds, as they are associated with an additional 256 bps decrease[13].

In conclusion, this paper showcases some interesting results in the field of sustainable finance. Undoubtedly, further research in this area is important to better the understanding of the differential effect interest rates have on the pricing of green conventional bonds. Given the mutual consensus that green investments must increase drastically towards the goal of reaching a net-zero economy by 2050 (Juvyns, 2023), it will be fascinating to follow the evolving demand for green bonds in the years to come. Moreover, green bonds are a relatively

[13] Table 13

new financial instrument, and our study includes a limited number of the global bond market. Future research can exploit the growing amount of data and subsequently provide stronger evidence of how interest rates impact bond prices in different regional markets. Finally, as our study is exclusively quantitative, a qualitative approach could further add new insights into global bond markets and the pricing of such securities. Future research may also investigate other types of sustainable securities and their respective pricing, such as transition bonds or sustainability-linked bonds, helping in the transition towards a more sustainable planet.

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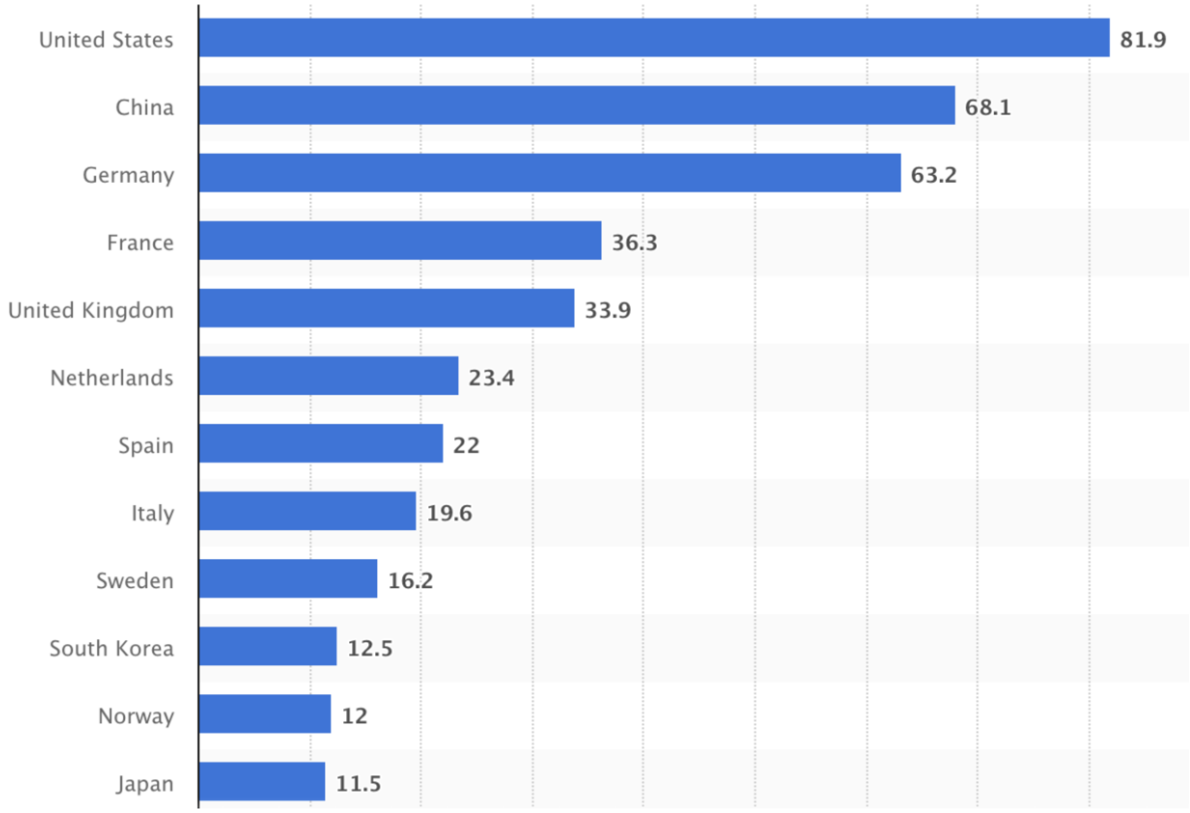
Appendix

A1 Global green bond issuance 2021

Figure A1.1 Green bond issuance by country 2021



(Statista, 2022a)

A2 Variable description

Table A2.1 Variable description

Variable Name	Variable Description
Ask_price	Ask price
Bid_price	Bid price
Bond_id	Number identifying each bond
Coupon	Coupon rate
Duration	Duration of bond
Green_dummy	Dummy variable equal to 1 if green bond and equal to 0 if conventional
Int_rate_green_dummy	Interaction term for Interest rate and Green dummy (Interest_rate x Green_dummy)
Interest_rate	Country specific interest rate
ISIN	International Securities Identification Number for each bond
Issue_date	Issue date of the bond
Issuer	Issuer name
Issuer_industry	Industry of bond issuers
Liquidity_proxy	Liquidity proxy created from bid-ask prices
LN Amount_issued	LN Amount issued (US Dollars)
Maturity_date	Maturity date of the bond
Mid_price	Mid price ((Ask price + Bid price)/2)
Month	Month (to set time variable)
Pair_nr	Number identifying each pair of green and conventional match
Time	Number that identifies time period
TTM	Time to maturity (in years)
Year	Year (to set time variable)

A3 Issuer industry

Figure A3.1 Issuer industry Nordics

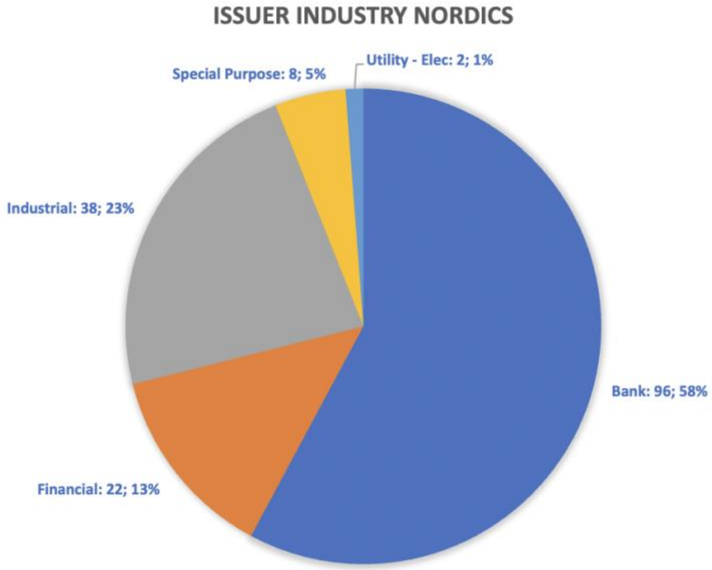
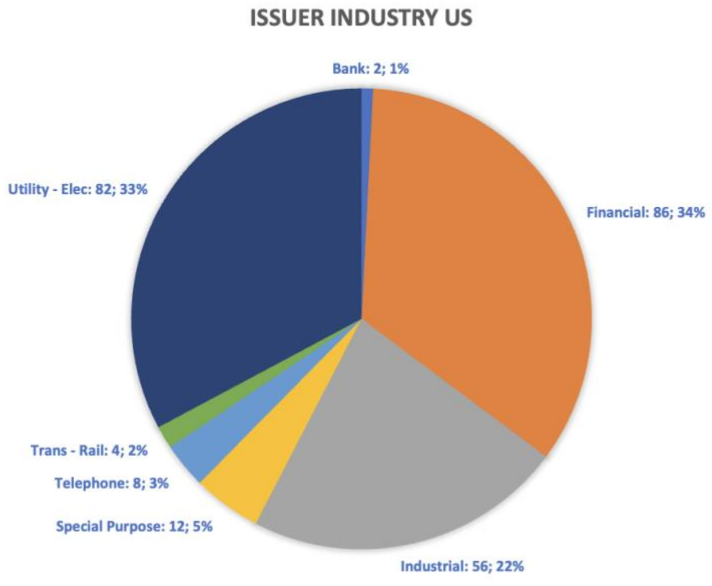


Figure A3.2 Issuer industry US



A4 Credit ratings

Figure A4.1 Credit ratings

Moody's		S&P		Fitch		Rating description	
Long-term	Short-term	Long-term	Short-term	Long-term	Short-term		
Aaa	P-1	AAA	A-1+	AAA	F1+	Prime	Investment-grade
Aa1		AA+		AA+		High grade	
Aa2		AA		AA			
Aa3		AA−		AA−			
A1		A+	A-1	A+	F1	Upper medium grade	
A2		A		A			
A3	P-2	A−	A-2	A−	F2		
Baa1		BBB+		BBB+		Lower medium grade	
Baa2	P-3	BBB	A-3	BBB	F3		
Baa3		BBB−		BBB−			
Ba1	Not prime	BB+	B	BB+	B	Non-investment grade speculative	Non-investment grade aka high-yield bonds aka junk bonds
Ba2		BB		BB			
Ba3		BB−		BB−			
B1		B+		B+		Highly speculative	
B2		B		B			
B3		B−		B−			
Caa1		CCC+	C	CCC	C	Substantial risks	
Caa2		CCC				Extremely speculative	
Caa3		CCC−				Default imminent with little prospect for recovery	
Ca		CC					
		C					
C		D	/	DDD	/	In default	
/				DD			
				D			

(Duggan, 2016)