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Unveiling the Liquidity Greenium:

Exploring Patterns in the Liquidity of Green versus Conventional Bond

Annalisa Molino, Lorenzo Prosperi, Lea Zicchino

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Abstract

While previous studies have mainly focused on the existence of a premium in the yield of green bonds, we test whether green bonds traded in the secondary market benefit from a 'liquidity greenium', i.e. they are more liquid compared to conventional bonds. To this end, we conducted several tests to identify patterns in both the cross-section and time series dimensions of our data set of global bonds issued between 2009 and 2022. We found evidence that green bonds issued by governments and supranationals are more liquid; this result generally does not hold for corporate bonds, with the exception of those issued by companies operating in the energy sector. Moreover, a liquidity premium for corporate green bonds exists if there is an external verification or alignment with international standards, or a proven environmental reputation of the issuer. In the time series dimension, we found that the liquidity premium of corporate green bonds has increased during periods of higher market illiquidity and after the recent monetary policy strategy of the ECB in favour of green assets. Finally, we found evidence that the liquidity of conventional bonds improves for firms that announce the issuance of green bonds, but only in the case of multiple issues.

Keywords: Green bonds, Liquidity, Sustainable finance.

JEL Classification: C33; G12; G14; Q56

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1. Introduction

The green bond market has grown significantly since the first green bond was issued in 2007, supported by the global commitments made in Paris in 2015 (Paris Climate Agreement). By combining standard bond features with a requirement to use the proceeds to finance green projects, green bonds are seen as an important tool for mobilising private capital to support the transition to a low-carbon economy. Despite the growth of the market, there is still a lack of standardised definitions, which can create uncertainty for investors about the green credentials of the bonds (greenwashing risk). There is growing interest and academic evidence on the relative performance of these bonds in terms of financial returns for investors and whether they can improve the overall performance of an investor's portfolio. In particular, previous studies have focused on providing evidence of the existence of a yield premium, or 'greenium' which means that green bonds may offer a lower market return than conventional bonds due to their special feature of investing proceeds in green projects.

In this paper, we investigate another characteristic of these bonds, their liquidity. The purpose of our analysis is to determine whether green bonds offer investors enhanced liquidity relative to conventional bonds with similar characteristics. If so, we say that green bonds offer a liquidity premium, or a 'liquidity greenium'. More specifically, our goal is to understand under which conditions on issuer and bond characteristics this liquidity greenium exists in the cross-section of observed bid-ask spreads. We are also interested in understanding whether this premium varies over time, under different market conditions and in response to policy changes on environmental issues. Understanding the liquidity characteristics of green bonds is extremely important. Evidence of greater liquidity means that not only do green bonds offer investors the opportunity to have a positive impact on the environment but also the opportunity to benefit from a liquidity premium, which means they can more easily sell their positions when needed without incurring substantial losses.

In principle, the existence of a liquidity greenium could be justified for several reasons. First, increased attractiveness to investors could explain higher demand and volumes for this type of bond. Second, issuing a green bond requires a higher level of disclosure. The existing literature suggests that better disclosure could mitigate the asymmetric information problem, leading to better secondary market liquidity (Diamond and Verrecchia, 1991). Despite the importance of this research question, it has not been thoroughly explored in the literature. Most of the literature on green bonds focuses on the yield premium, i.e. on the existence of a negative difference between the yield of a green bond and a conventional bond with comparable characteristics, while few studies investigate the liquidity of green bonds, and find mixed evidence. Wulandari et al. (2018) analyse the liquidity of green bonds, but only to the extent that it might affect the yield premium. They control for credit risk, bond-specific characteristics, and macroeconomic variables using two liquidity measures, the bid-ask spread and the Lesmond, Ogden and Trzcinka measure or LOT (Lesmond et al., 1999), and conclude that liquidity risk is negligible for green bonds. Bachelet et al. (2019) provide some preliminary findings on the existence of a liquidity premium. The authors find that green bonds, especially those issued by governments or supranational entities, are more liquid while corporate green bonds have less favourable characteristics in terms of liquidity unless they are certified. The

European Central Bank (2020) calculates the difference in bid-ask spreads between green and conventional bonds of the same issuer with similar characteristics and finds that green bonds do not consistently differ in terms of liquidity. The European Securities and Markets Authority (ESMA, 2021) compares the liquidity of green and conventional EUR corporate bonds issued by green bond issuers using proxy indicators and finds that green bonds appear to be less liquid. The Climate Bond Initiative (Harrison, 2021) finds that in 2020 green bonds traded more frequently and had tighter bid-ask spreads than similar bonds without the green label. Both reports compare average liquidity proxies of green and conventional bonds without controlling for bond and issuer-specific characteristics, implying that any difference in liquidity may not be due to the green bond status. The impact of disclosure quality and readability of green bonds issuance documents on their liquidity was analysed by Lebelle et al. (2022). The authors found that disclosure of green bond frameworks and annual reports and their readability increase bond liquidity. Instead, there is more evidence of the impact of the ESG performance and disclosure of the firm and stocks' liquidity. For example, Bonagura et al. (2021) investigated the relationship between two different measures of stock liquidity, such as the bid-ask spread and the Amihud Illiquidity ratio, and various indicators of firm 'greenness'. Their panel data analysis shows that green firms exhibit higher liquidity, a significant finding across different measures of liquidity, environmental performance, and model specifications. Krueger et al. (2021) documented a significant positive effect of ESG disclosure mandates on firm-level stock liquidity, with the strongest effects when the disclosure requirements are implemented by government institutions and coupled with strong enforcement by informal institutions.

We contribute to the literature by investigating the relationship between liquidity and green bond label, and by exploring potential patterns of liquidity premia in bond and issuer characteristics. The main empirical challenge is that green bonds are highly heterogeneous, making it difficult to find comparable non-green bonds to measure a liquidity premium. For this reason, we use standard panel data econometrics, which allows us to estimate the effect of the green bond label while controlling for other characteristics that may affect market liquidity following the approach of Kapraun et al. (2021). Our results suggest that green bonds are more liquid than conventional bonds with similar characteristics. However, we find that without controlling for the credibility of the green bond label or the environmental performance of the issuer, this result only holds for bonds issued by governments, whose reputation may reduce information asymmetries on the use of proceeds for effective green projects (Fatica et al., 2021; Bachelet et al., 2019; Kapraun et al., 2021). Among corporate bonds, we find higher liquidity for assets issued by firms in the energy sector, possibly because these issuers are considered as more credible in terms of the greater impact from the use of proceeds. These results are consistent with the findings of Bachelet et al. (2019), but we improve their analysis on liquidity along several dimensions. First, we examined the pattern of liquidity premia across different sectors and by controlling for the 'green' reputation of the issuer, as measured by ESG scores. Moreover, we present several findings on the time series pattern of liquidity premia. Finally, compared to Bachelet et al. (2019), we do not rely on a matching approach where the empirical hypotheses are tested on a sample of green bonds matched with their closest conventional counterparts, which results in very few cases being considered in the analysis. Regarding the credibility of the green label, we find that green bonds with an external review, which can take the form of certification or third-party verification, benefit from a liquidity greenium, unlike self-labelled bonds. Corporate issuers can only benefit from a narrowing bid-ask spread if the bond is certified. We also consider the effect of the environmental reputation of the issuer and find that green bonds issued by companies with a good environmental score benefit from a negative liquidity premium, and that the effect on the bid-ask spread is not explained by the score itself. Thus, companies that certify their commitment to using the proceeds for green projects or that have a strong environmental reputation may also benefit from higher liquidity in the secondary market. On the time series dimension, we study several phenomena that can affect the liquidity premium of green and conventional bonds. First, we investigate whether the liquidity greenium increases during periods of higher market illiquidity/stress. There is consensus on the fact that liquidity premia vary considerably over time, increasing particularly during market downturns (Rösch, 2012; Vayanos, 2004). Investors often use the term ‘flight to liquidity’ to describe these situations, indicating that they have an appetite for holding liquid assets. If green bonds are more liquid than conventional bonds, we should observe an increase in the liquidity greenium during periods of higher aggregate illiquidity. We find that the green bond liquidity premium does not increase for sovereign bonds, but it does for corporate green bonds. This result could be relevant for banks when conducting liquidity stress testing as part of their liquidity risk management and Internal Liquidity Adequacy Assessment Process (ILAAP). For instance, banks supervised by the European Central Bank will be required by 2024 to include climate risk in their ILAAP framework: the design of climate stress scenarios is an essential element of this process, and the ability to discriminate which haircuts to apply to green and non-green bonds, is crucial to estimate the liquidity reserve of an institution, particularly under a climate stress scenario. From a regulatory standpoint, the Basel liquidity indicators (i.e. Liquidity Coverage Ratio, Net Stable Funding Ratio, Monitoring Tools) may need to capture in the future a different degree of liquidity among bonds, based on their ‘greenness’ possibly in line with the choices that will be made in the area of monetary policy. In this vein, we also examine whether policy changes can affect the liquidity levels of these bonds. In this regard, we find that following the announcement of the European Central Bank's Monetary Policy Strategy Review, in which the ECB established a dedicated workstream on climate change, green bonds benefit from a lower bid-ask spread when compared to ECB-eligible conventional bonds. Finally, we examined whether the announcement of a green bond issue leads to improved liquidity conditions for the issuer's conventional bonds. Previous research has shown that the market views the issuance of green bonds as a credible indication that the issuer is genuinely integrating sustainability considerations into its business model. If this is the case, we would expect that firms with listed securities would experience increased investor demand and, consequently, an improvement in their liquidity conditions following the issuance of green bonds. We find that this hypothesis is supported by our data, but for corporate issuers this result only holds for ‘experienced’ green bond issuers, i.e. for those firms that have issued a green bond before. This confirms that environmental reputation does play a role in explaining the existence of a liquidity greenium.

The paper is organised as follows. In Section 2 we describe the methodology and explicitly state our empirical hypothesis that we test in the paper. In Section 3 we describe the data set used for the analysis and in Section 4 we present some descriptive statistics on these data. Section 5 presents and discusses our main findings. Section 6 presents two robustness checks that verify our results on a larger data set, while the last section presents the conclusions.

2. Methodology

In this section, we explicitly state the research questions we are interested in answering. First, we want to understand whether green bonds are more liquid than conventional bonds and how this result varies with issuer and bond characteristics. In particular, we defined a set of empirical hypotheses related to this general question, which we include in Section 2.1 on cross-sectional evidence on green bond liquidity. Second, we exploited the time series dimension of our data set to address other empirical questions, such as the extent to which the liquidity premium of green bonds changes according to market conditions or the extent to which policy decisions, like the ECB monetary policy review, might affect the liquidity level of green bonds. Finally, similar to Tang and Zhang (2020), we would like to understand whether the liquidity of the issuer's conventional bonds improves after the announcement of a green bond issuance. This may suggest that the issuance acts as a signal of the sustainability of the firm, which would improve the liquidity of each financial instrument issued by the firm. We address these empirical issues in Section 2.2 on time series evidence on green bond liquidity. Importantly, in our baseline result, we consider the bid-ask spread as a measure of liquidity. Bid-ask spread is an order-based measure of liquidity, and more specifically a measure of transaction costs (Galliani et al., 2014; Sarr and Lybek, 2002), and represents an estimate of the cost incurred by an investor to trade immediately. The literature has largely adopted this measure of liquidity for bonds, both conventional and green (Galliani et al., 2014; Doronzo et al., 2021; Fleming, 2001) and for equities (Bonagura et al., 2021; Tang and Zhang, 2020; Egginton and McBrayer, 2019; Siew et al., 2016). However, bid and ask prices were not available for all green and conventional bonds in our data set and this consistently reduced the sample size for our analysis, from almost 22 500 to around 5 000 bonds[4]. We also excluded bonds that have zero yields in both bid and ask prices in at least 30 % of the sample. As a result, our benchmark results focus on a subsample of bonds that are likely to be more liquid than a sample of excluded bonds. For this reason, we replicated our analysis by using order-based proxies, which should provide an estimate of the bid-ask spread, but that are based on price data rather than quote data (Goyenko et al., 2009; Galliani et al., 2014). For our robustness (see Section 6), we used *ZeroTradingDays* (*ZTD*), i.e. the proportion of days with zero returns (Lesmond et al., 1999), which is based on the idea that an investor will only trade if the cost of trading is lower than the expected profit.

[4] See Section 3 for a detailed description of the sample size.

2.1 Cross-Sectional evidence on the liquidity of green bonds

To test whether green bonds are more liquid than conventional bonds we estimated different specifications of a panel data regression model in which the dependent variable, the bid-ask spread, depends on a number of bond-specific characteristics, different types of fixed effects and, ultimately, the green bond label.

Panel data regression is a standard practice in the literature when investigating the effect of the green bond label on financial characteristics (Kapraun et al., 2021; Fatica et al., 2021). Other approaches adopt a matching technique (Bachelet et al., 2019; Pietsch and Salakhova, 2022) where green bonds are matched to one conventional 'closest' bond. However, we decided not to follow this approach due to the small sample size constrained by the availability of bid-ask spreads.

More specifically, we focused on the estimation of the following type of relationship using monthly data.

$$BidAsk_{b,t,i} = \beta_0 + \beta_1 Green_b + \beta_2 Maturity_{b,t} + \alpha_3 Size_b + \alpha_4 Curr_b + \alpha_5 Rating_{b,t} + \alpha_6 IsSecured_b + \varphi_t + \gamma_i + \varepsilon_{b,t,i} \quad (1)$$

where b is the bond, t is time, i is the issuer. We were interested in the coefficient associated with the green bond dummy, $Green_b$. $Maturity_{b,t}$ is the time to maturity of the bond. We then introduced a set of bond-specific fixed effects: $Size_b$ is a variable that measures the issue size of the bond (logarithm of the amount in USD), $Curr_b$ is the principal currency (EUR, USD, or other currencies), $Rating_{b,t}$ is the rating of the instrument at time t, $IsSecured_b$ is a dummy variable that is equal to one if a bond has some underlying collateral, zero otherwise. We also included a time effect φ_t (Year-Month) and issuer-specific fixed effects γ_i. In the estimation we always used clustered standard errors at the issuer level.

We explicitly formalise our testable hypothesis. The first research question we would like to address is whether green bonds are more liquid than conventional bonds with comparable characteristics, i.e. whether they benefit from a liquidity greenium.

Hypothesis 1 (Liquidity greenium for green bonds in the full sample). *Green bonds are more liquid than conventional bonds after controlling for differences in time to maturity, rating, bond-specific characteristics, time and issuer fixed effects. This implies testing that β_1 in equation 1 is negative and significant.*

The evidence of higher liquidity of green bonds from the estimation of equation 1 in the full sample, does not necessarily imply that this result holds for every bond in our sample. In particular, we wanted to understand whether issuer characteristics play a role in explaining our results. We investigated this by estimating equation 1 on different sub-samples of government and corporate bonds. For corporate bonds, we were interested in bonds issued by both financial and non-financial corporations. In the latter case, we explored whether there was evidence of better liquidity performance for bonds issued by firms in the energy and non-energy sectors, as we expected that in the former case market participants would be more interested in financing investments that could have a more direct and tangible impact on reducing global CO_2 emissions.

Hypothesis 2 (Liquidity greenium for green bonds across different issuer types). *Green bonds are more liquid than conventional bonds after controlling for differences in time to maturity, rating, bond-specific characteristics, time and issuer fixed effects. This result holds for different subsamples of issuers: governments and corporates (financial and non-financial). This implies testing that β_1 is negative and significant in equation 1 estimated on different subsamples of bonds according to issuer type.*

To anticipate our result, we found that there is evidence of a liquidity premium for green bonds (a liquidity greenium) at the aggregate level, but this is mostly explained by bonds issued by sovereign entities. Among corporates, only firms in the energy sector benefit from better liquidity conditions in the markets compared to conventional bonds. A possible explanation for this result is that the lack of information on ESG credentials and the risk of greenwashing discourage markets from investing in these bonds. External counterparties that certify green bond issues could play an important role in reducing asymmetric information in the markets (Fatica et al., 2021; Siew et al., 2016). Therefore, we explicitly tested this hypothesis by running a specific model both on the full sample and the restricted sample.

$$\begin{aligned} BidAsk_{b,t,i} = {} & \beta_0 + \beta_{1,1}Certified_b + \beta_{1,2}Aligned_b + \beta_{1,3}SelfLab_b \\ & + \beta_2 Maturity_{b,t} + \alpha_3 Size_b + \alpha_4 Curr_b + \alpha_5 Rating_{b,t} + \alpha_6 IsSecured_b + \phi_t + \gamma_i + \varepsilon_{b,t,i} \end{aligned} \tag{2}$$

where $Certified_b$ = 1 if the green bond is certified by the Climate Bond Initiatives (CBI), $Aligned_b$ = 1 if the green bond is CBI aligned and $SelfLab_b$ = 1 if there is no external verification and the status of 'green bond' is self-declared by the firm.

In line with standard practice in the literature, we adopted the Climate Bond Initiative (CBI) certification procedure to measure the quality of the green bond issuance. CBI is an international organisation working to mobilise global capital for climate action. Its strategy is to develop a large and liquid green and climate bond market to facilitate investment in projects and assets needed to transition to a low-carbon and climate-resilient economy. In particular, the CBI Standard and Certification Scheme is a scheme for bonds, designed as a tool for investors and governments to help them prioritise investments that make a real contribution to tackling climate change. CBI Certified Green Bonds are certified under the CBI Standard and are considered the highest standard of green bonds. CBI Aligned Green Bonds are not certified but have been deemed by CBI to meet the screening requirements and are the next highest standard of green bonds. Self-labelled bonds are labelled as green by the issuer but do not meet CBI criteria. We confirm the role of certification with the following formal statement.

Hypothesis 3 (The role of certification in the liquidity premium of green bonds). *External certification improves the liquidity of green bonds relative to conventional bonds in the full sample and across issuer types. This implies that we expect $\beta_{1,1} < \beta_{1,2} < \beta_{1,3}$ for all types of bonds especially for those issued by corporations. Moreover, we expect $\beta_{1,1}$ and $\beta_{1,2}$ to be negative and significant.*

A related question is whether environmental reputation might play a role in explaining the existence of a liquidity premium for corporations. More specifically, we are interested in understanding whether green bonds issued by firms with high environmental scores do benefit from better liquidity conditions compared to firms with low environmental scores. To this end, we estimated the following regression:

$$BidAsk_{b,t,i} = \beta_0 + \beta_0^H ScoreTop_i + \beta_1 Green_b + \beta_1^H Green_b \times ScoreTop_i$$

$$+ \beta_2 Maturity_{b,t} + \alpha_3 Size_b + \alpha_4 Curr_b + \alpha_5 Rating_{b,t} + \alpha_6 IsSecured_b + \phi_t + \gamma_i + \varepsilon_{b,t,i} \quad (3)$$

where $ScoreTop_i$ is a dummy variable that has a value of 1 if the Refinitiv Environmental Score associated with the issuer of the bond is above 75, which is the minimum threshold in the Refinitiv scale to define a firm as 'top-performing' in terms of environmental performance. Since Refinitiv scores are only available for companies, we ran model 3 only on corporate bonds.

Hypothesis 4 (The role of reputation in the liquidity premium of green bonds). *The liquidity premium of green bonds is higher for firms with higher environmental scores. This implies that β_1^H in equation 3 is negative and significant.*

To anticipate our findings, we found evidence that certification/alignment with international standards and the firm's reputation on environmental performance are key to making corporate green bond issuance more attractive to investors and improving the liquidity of these bonds.

2.2 Time Series evidence on green bonds liquidity

In what follows, we present a number of test hypotheses related to the behaviour of our proxy for liquidity over time for green and conventional bonds. To begin with, we document that there is some evidence of better liquidity of green bonds relative to conventional bonds in the cross-section, but we are also interested in understanding how the liquidity premium of green bonds, if it exists, changes according to market conditions. The liquidity of green bonds may improve relative to conventional bonds in periods of higher market stress/illiquidity if these types of bonds are perceived as 'safe haven' assets. To test this hypothesis, we followed the approach proposed by Galliani et al. (2014). The authors investigated the relationship between the liquidity of individual bonds and the liquidity of the market, by studying the interaction of bond characteristics with a dummy that identifies periods of high market illiquidity. They found that illiquidity is higher for bonds with longer durations and lower ratings, especially during periods of market stress.

To perform this test, we identified periods of market stress and low aggregate liquidity by measuring over time a weighted average of the bid-ask spread of the bonds in our sample and defined a time dummy equal to one if the proxy considered is above a certain threshold (75th) of its empirical distribution. Thus, we extended model 1 as follows:

$$BidAsk_{b,t,i} = \beta_0 + \beta_0^S Stress_t + \beta_1 Green_b + \beta_1^S Green_b \times Stress_t + \beta_2 Maturity_{b,t} + \alpha_3 Size_b + \alpha_4 Curr_b + \alpha_5 Rating_{b,t} + \alpha_6 IsSecured_b + \alpha_3^S Size_b \times Stress_t + \alpha_4^S Curr_b \times Stress_t + \alpha_5^S Rating_{b,t} \times Stress_t + \alpha_6^S IsSecured_b \times Stress_t + \phi t + \gamma i + \varepsilon_{b,t,i} \quad (4)$$

We formalise this hypothesis as follows.

Hypothesis 5 (Liquidity of green bonds in times of stress). *The liquidity premium of green bonds increases in times of stress. This implies that β_1^S in equation 4 is negative and significant.*

Regarding the existence of better liquidity conditions for green bonds, we asked whether policy changes can influence the level of liquidity of these bonds. To this end, we examined the effect of the announcement of the outcome of the Monetary Policy Strategy Review of the European Central Bank.

The Monetary Policy Strategy Review was a comprehensive assessment of the ECB's monetary policy framework, which had not been revised since 2003. On 8 July 2021, the ECB communicated to the markets its new monetary policy strategy, which aims to ensure that the Euro Area's monetary policy framework is fit for purpose in the face of new challenges. As part of the review, the ECB established a dedicated workstream on climate change to assess how it could be taken into account in the monetary policy framework. The workstream on climate change produced several important recommendations in the areas of disclosure, risk assessment, collateral framework, and corporate sector asset purchases. Regarding the collateral framework, the ECB committed to consider climate change risk when reviewing the valuation and risk control frameworks for assets used as collateral by counterparties for Eurosystem credit operations, and to continue to monitor market developments in sustainability products and to support innovation in the area of sustainable finance[5]. The ECB also committed to adapt the framework for the allocation of corporate bond purchases to incorporate climate change criteria, including the alignment of issuers with EU legislation implementing the Paris Agreement through climate change-related metrics or commitments by issuers to such targets. The implementation of the action plan is meant to be in line with progress on the EU policies and initiatives in the field of environmental sustainability disclosure and reporting, including the Corporate Sustainability Reporting Directive, the Taxonomy Regulation, and the Regulation on sustainability-related disclosures in the financial services sector. In parallel, on 6 July 2022 the European Commission adopted the new Sustainable Finance Strategy, which sets out several initiatives to tackle climate change and other environmental challenges. On the same day, the Commission adopted a proposal for a Regulation on a voluntary European Green Bond Standard, which aims to create a high-quality voluntary standard available to all issuers (private and sovereign) to facilitate the financing of sustainable investments. We expect that following the ECB's change in the monetary policy strategy, green bonds have become more attractive to banks with access to ECB funding. We expect that this increase in demand for green bonds has led to an increase in the investor base

[5] On 22 September 2020 the ECB decided to accept sustainability-linked bonds as collateral for Eurosystem credit operations and for outright purchases for monetary policy purposes, already signalling its support for innovation in the area of sustainable finance. The decision applies from 1 January 2021.

for these assets and, therefore, trading these bonds should be less costly. To investigate this issue, we followed the approach of Eliet-Doillet and Maino (2022). In particular, we defined a dummy Post, which takes the value 1 after the announcement date.

$$BidAsk_{b,t,i} = \beta_0 + \beta_1 Green_b + \eta Green_b \times Post_t + \beta_2 Maturity_{b,t} + \alpha_3 Size_b + \alpha_4 Curr_b + \alpha_5 Rating_{b,t} + \alpha_6 IsSecured_b + \phi_t + \gamma_i + \varepsilon_{b,t,i} \quad (5)$$

We estimated equation 5 using a sample of corporate bonds on the market in the period between March 2009 and September 2021. We then further restricted our estimation set by focusing only on bonds that are eligible as ECB collateral. We therefore state our hypothesis on the effect of the ECB announcement on the liquidity of green bonds:

Hypothesis 6 (Liquidity of green bonds and policy announcements). *The liquidity premium of ECB-eligible green bonds increases after the ECB announces its action plan to include climate change considerations into its monetary policy strategy. This implies that $\eta < 0$ in equation 5 is negative and significant when the estimation sample is restricted to the list of ECB-eligible bonds.*

In principle, the coefficient could be negative and significant on the full sample for both ECB-eligible and non-eligible bonds, due to some spillover effect. For example, when looking at the effect of the asset purchase programme De Santis and Zaghini (2021) found that direct purchases of corporate bonds by the ECB reduce credit spreads not only for eligible bonds, but also to a lesser extent for non-eligible bonds.

Finally, we state our last testing hypothesis. So far, our empirical analysis has focused on determining whether green bonds benefit from a liquidity greenium relative to conventional bonds. We do this by looking at the quoted bid-ask spreads of active bonds in the market. Some of the evidence we have found points to the existence of a liquidity premium under certain circumstances. This should suggest that if a corporate or sovereign issuer issues two identical bonds, but the second is green, we expect the latter to be more liquid. However, we found the size of the liquidity premium to be relatively small, around 4.3 bp in the full sample, compared to the average bid-ask spread in our sample (47.6 bp). In principle, this is not surprising. Even if the proceeds of green bonds are earmarked for specific projects, the repayment is associated with the issuer and not with the project. The credit risk of the issuer, which is common to both conventional and green bonds, is the key driver of bond liquidity and yields. This also implies that if the issuance of green bonds signals that the issuer has a more sustainable business model, this might reduce the perceived credit risk of the issuer and make both green and conventional bonds more liquid in the market (Doronzo et al., 2021). Previous literature suggests that the issuance of green bonds is perceived by the markets as a credible signal that the issuer is seriously incorporating sustainability considerations into its business model (Kuchin et al., 2019; Flammer, 2021; Zhou, 2019). If this is the case, we expect that listed corporate securities could benefit from higher investor demand following the issuance of a green bond, thereby improving their liquidity conditions. This mechanism was not investigated in the previous regressions. Tang and Zhang (2020) found this result to hold when looking at the liquidity of the issuer's shares. Compared to Tang and Zhang (2020), we replicated his set-up by focusing on the liquidity of conventional bonds.

To be more specific, we looked at the bid-ask spread of conventional bonds around the announcement of the issuance of a green bond. We focused only on conventional bonds for which the issuer in our sample has issued at least two green bonds. We used a balanced panel, looking at the time series of the bid-ask spread of the conventional bonds in a pre-specified window around the announcement of the green bond's issue. We then defined a dummy $Post_{it}$ that has a value of 1 for conventional bond i after the announcement of the green bond's issue.

$$BidAsk_{b,t,i} = \beta_0 + \beta_0^P Post_{i,t} + \beta_2 Maturity_{b,t} + \alpha_3 Size_b + \alpha_4 Curr_b + \alpha_5 Rating_{b,t} + \alpha_6 IsSecured_b + \phi_t + \gamma_i + \varepsilon_{b,t,i} \quad (6)$$

We formalise this in hypothesis 7.

Hypothesis 7 (Liquidity of conventional bonds after green bond issuance). *The liquidity of conventional bonds of green bond issuers improves significantly in the one-year horizon. This implies that* β_0^P *in equation 6 is negative and significant.*

Due to the event study nature of the approach, unlike the previous models we used weekly data to test hypotheses 6 and 7.

3. Data set

For this study, we collected data on plain vanilla fixed coupon green bonds issued globally between January 2009 and May 2022 from Refinitiv. To avoid selection bias, we only included conventional bonds issued by entities that also issued green bonds. The initial sample contained 21 202 bonds, of which 1 343 were green. We downloaded from Refinitiv the time series of bid and ask prices and the main characteristics of the bonds: issue date, maturity date, amount issued, principal currency and collateral. We also downloaded the time series of the bond ratings, as provided by Moody’s or Fitch, and defined 11 categories with 1 being the top rating and 10 the worst rating (default state). Bonds that were not rated or no longer rated (rating withdrawn) were assigned to category 0. If we had a rating different from 0 from both agencies, we kept the worst one. To test our hypothesis, we only considered bonds with available data on bid and ask price, which reduced our sample to 4 318 bonds, of which 637 were green. Next, we excluded the bonds whose other main characteristics were not available. To be more specific, we only had information on the bond rating for about 50% of the bonds. Finally, after cleaning, we only kept in the final sample issuers that have both green and conventional bonds. We calculated the bid-ask spread daily as follows:

$$BidAsk_{b,t,i} = 100 \times \frac{Ask_{b,t,i} - Bid_{b,t,i}}{(Ask_{b,t,i} + Bid_{b,t,i})/2} \quad (7)$$

where $Ask_{b,t,i}$ and $Bid_{b,t,i}$ are the daily ask and bid prices of bond *b*, listed at time *t* and issued by issuer *i* and then we take the monthly average. To mitigate the effect of outliers, we windsorised the time series of bid-ask spreads[6].

[6] We apply windsorisation to the observations larger than four times the interquartile range + median at daily level.

To measure the credibility of the green label, we extracted from Refinitiv information on the alignment to CBI (CBI Certified, CBI aligned, or self-labelled). Next, we extracted information on the type of issuer and the industry sector. We distinguish between government and supranational bonds, including governments, treasuries, central banks, supranational organisations, agencies and municipalities, and corporate bonds. We then split corporate firms between financial companies, including bank and other financial companies, and non-financial companies, including energy and electricity, and other non-financial companies (manufacturing, consumer goods, services, telephony, transport). To do this, we used the Refinitiv Business Classification. To measure the ESG and green reputation of the issuer, we use the time series of the ESG and environmental score calculated by Refinitiv. The score, a number on a scale between 0 and 1, measures a company's relative performance and commitment based on reported data[7]. Companies with a score above 0.75 are considered leaders and those with a score below 0.25 are considered laggards.

4. Descriptive statistics

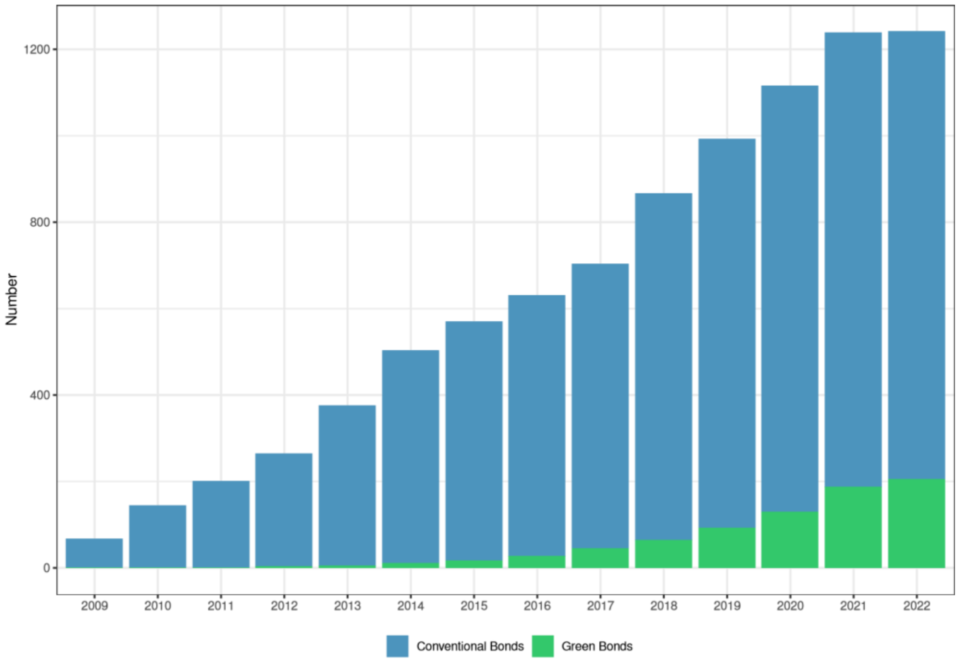
The final sample consisted of 1 764 bonds, of which 220 were green, amounting to around USD 150 billion. In some specifications, the number of bonds was further reduced due to the unavailability of data. Figure 1 shows the number and volume of bonds (in terms of the amount issued) per year in our sample. While the number of conventional bonds issued by green bond issuers has remained relatively stable over time, green bonds have increased steadily since 2013.

Table 1 provides descriptive statistics for the green and conventional bonds. The average green bond in the sample has a maturity of around 12 years, and an issuance size of around USD 655 million, while the average conventional bond has shorter maturity and larger size. On average, green bonds in the sample have larger bid-ask spreads than conventional bonds.

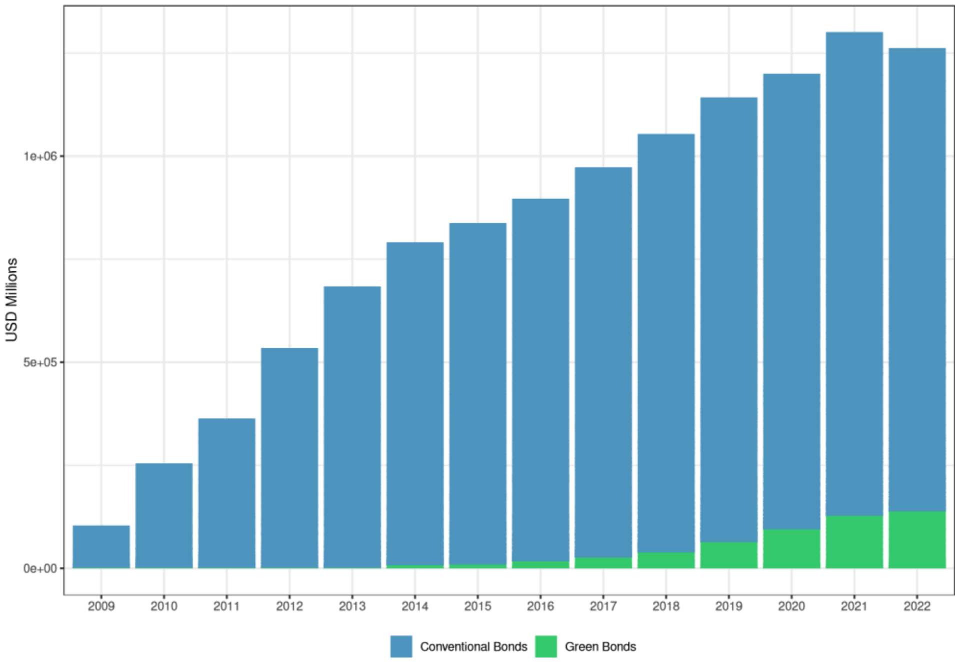
[7] Details can be found on the following link: https://www.refinitiv.com/content/dam/marketing/en$_u$s/documents/ methodology/refiesg − scores − methodology.pdf

Figure 1. Number and amount of bonds active in the market in each year of the sample

(a) Number



(b) Amount



Notes: This figure shows the number and the amount of active bonds in the markets for each year in our sample. This sample size is derived by selecting from the universe of bonds only green and conventional bonds issued by green bond issuers. The final sample size is further reduced after matching with relevant information for our testable hypothesis (bid-ask spread, rating, etc.) and after cleaning.

Table 1. Descriptive statistics

(a) Green bonds

Statistic	N	Mean	St. Dev.	Min	Max
Bid-Ask Spread (%)	220	0.5	0.3	0.04	2.1
Maturity (Years)	220	12.1	11.9	1.5	98.8
Amount Issued (USD Mln)	220	655.3	652.7	17.3	5,349.5

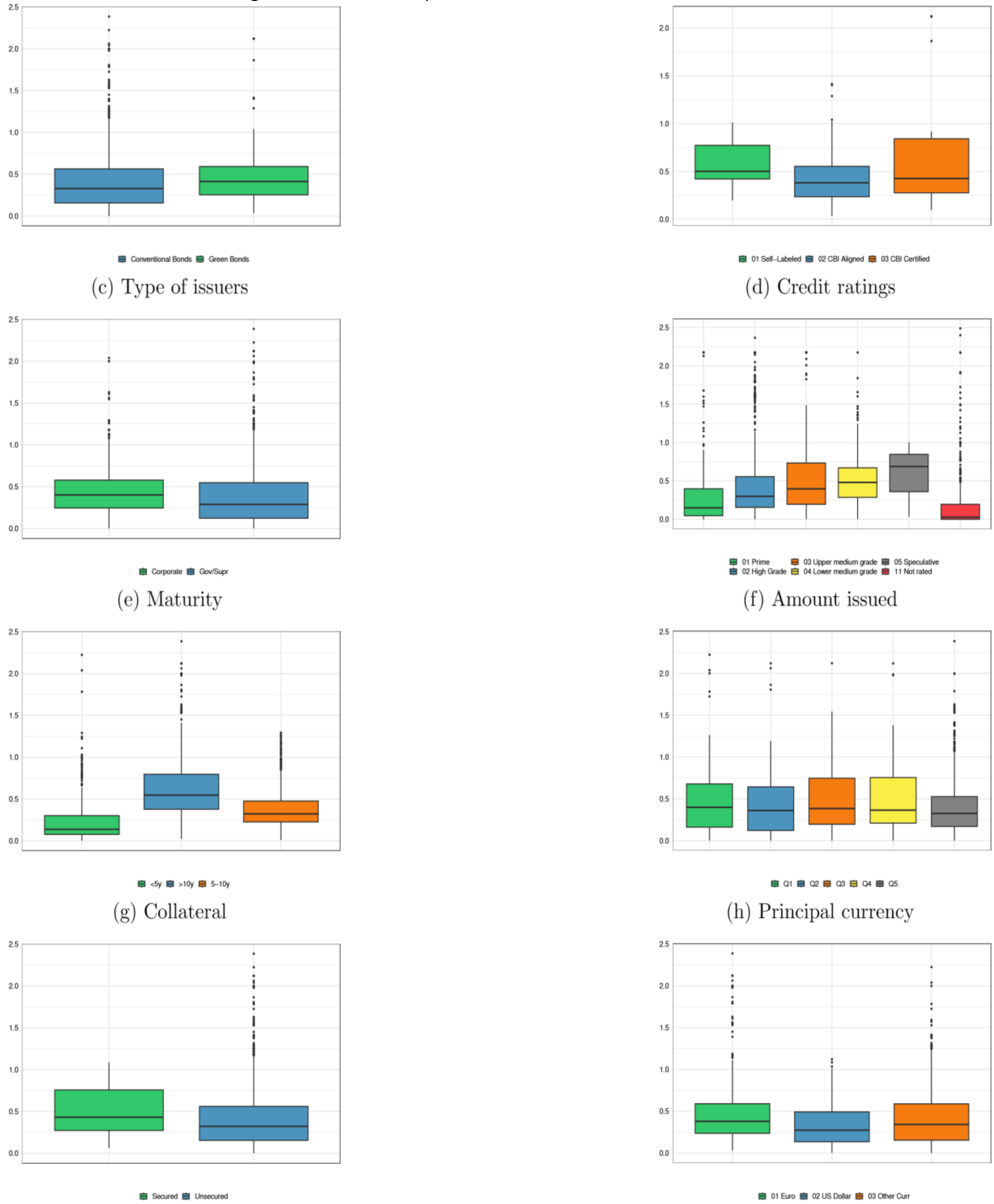
(b) Conventional bonds

Statistic	N	Mean	St. Dev.	Min	Max
Bid-Ask Spread (%)	1,544	0.4	0.3	0.001	2.4
Maturity (Years)	1,544	8.5	9.6	0.05	96.9
Amount Issued (USD Mln)	1,544	1,273.0	3,197.1	0.8	26,747.4

Notes: We present the summary statistics of our sample of bonds that we used to test our hypothesis. The sample is derived by selecting from the universe of bonds only green and conventional bonds issued by green bond issuers. The final sample size is further reduced after matching with relevant information for our testable hypothesis (bid-ask spread, rating, etc) and after cleaning.

This is also evident from Figure 2, which shows the distribution of the bid-ask spread for bonds with different underlying characteristics, which are used as control variables in the regression analysis. Furthermore, CBI-aligned and certified green bonds have, on average, a lower bid-ask spread than self-labelled green bonds. As expected, corporate bonds are less liquid than government bonds. Furthermore, the bid-ask spread decreases with credit rating and issue size and increases with time to maturity. We also found that illiquidity appears to be higher for unsecured bonds, and slightly higher for euro-denominated bonds.

Figure 2. Bid-ask spreads and bond characteristics



Notes: In this boxplot, we compare the cross-section distribution of the bid-ask spreads for bonds with different underlying characteristics, which are described in more detail in Section 2. The characteristics of the bonds are: type of bond (conventional, green, CBI aligned or certified), issuer characteristics (corporate vs sovereign), issue characteristics (most recent rating, maturity at issuance, amount issued in quintiles of the bonds issued in the same month, collateral and principal currency).

These preliminary findings from the simple descriptive analysis are consistent with other papers in the literature. For example, there is substantial evidence that the liquidity of an instrument is negatively correlated with the credit quality due to a higher probability of default (Galliani et al., 2014; ESMA, 2012). Indeed, liquidity haircuts on collateral for central banks' refinancing operations are typically tightly correlated with credit ratings (European Central Bank, 2018; Federal Reserve Bank of New York, 2021). There is also evidence that smaller, longer-dated bonds issued a long time ago have a higher liquidity premium (Galliani et al., 2014; ESMA, 2012). This may be explained by the fact that longer-term bonds are more sensitive to changes in interest rates, and larger issues attract more investors and provide higher trading volumes.

Table 2a shows that the number of green bonds in our sample is balanced between governments and corporates, and, similar to conventional bonds, a large proportion of green issues are from the banking and energy sectors. We identified 25 green bonds that are certified by the CBI, as shown in Table 2b, of which only 3 were issued by corporates, while the majority are aligned. Refinitiv calculates an ESG score for 19 out of the 58 companies in our sample. Over the sample period, only 6 of these were on average leaders and 15 were laggards.

Table 2. Type of bonds

(a) Number of bonds by type of issuer

Issuer Type	Industry Type	Industry Sector	Conventional	Green	Total
Corporate	Financial	Banks	381	24	405
	Non-Financial	Other Fin	36	14	50
		Energy	178	51	229
		Non-Energy	72	18	90
Gov/Supr			877	113	990
All Sample			1544	220	1764

(b) Number of green bonds by type of label

Issuer Type	CBI Aligned	CBI Certified	Self-Labelled	Total
Corporate	81	3	23	107
Gov/Supr	84	22	7	113
All Sample	165	25	30	220

Notes: We present the summary statistics of our sample of bonds that we used to test our hypothesis. The sample is derived by selecting from the universe of bonds only green and conventional bonds issued by green bond issuers. The final sample size is further reduced after matching with relevant information for our testable hypothesis (bid-ask spread, rating, etc) and after cleaning.

5. Empirics

5.1 Cross-Sectional evidence on the liquidity of green bonds

Table 3 presents the results for our testing of hypothesis 1. The simple OLS regression of the bid-ask spread on the dummy in column (1) suggests a negative effect of the green label on the bid-ask spread, although it is not statistically significant. After controlling for the maturity of the bonds and the issue size in the regression specifications in column (2), the coefficient remains negative. The result does not change after including the bond and time fixed effects in columns (3) and (4). However, after including the issuer fixed effects, the negative coefficient in the regression specification (5) becomes significantly different from zero, indicating that green bonds are more liquid than comparable conventional bonds. The magnitude of the estimated coefficient in the full specification in column (6) suggests that the bid-ask spread of green bonds is about 4.3 bps lower than that of conventional bonds with similar characteristics. We therefore accept hypothesis 1, which states that there is a liquidity premium for green bonds at the aggregate level. Using a matching approach, Bachelet et al. (2019) also find that green bonds are generally more liquid than their matched twins.

Table 3. Baseline regression

	Dependent variable: Bid-Ask Spread					
	Measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Green	-0.020	-0.024	-0.027	-0.009	-0.056**	-0.043**
	(0.042)	(0.030)	(0.031)	(0.025)	(0.022)	(0.019)
Maturity		0.013***	0.015***	0.013***	0.017***	0.016***
		(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Amount		-0.040**	-0.031*	-0.045***	-0.046**	-0.046**
		(0.017)	(0.016)	(0.016)	(0.020)	(0.018)
Constant	0.425***	1.102***				
	(0.024)	(0.346)				
Bond FE			X			X
Time FE				X		X
Issuer FE					X	X
Green Bonds	220	220	220	220	220	220
Observations	86,057	86,057	86,057	86,057	86,057	86,057
R^2	0.0002	0.139	0.595	0.615	0.646	0.692
Adjusted R^2	0.0002	0.139	0.595	0.614	0.646	0.691

Notes: The table reports the regression results of equation 1 for different specifications where different covariates and fixed effects are included. Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

To test hypothesis 2, we ran separate regressions for government and corporate bonds, both financial and non-financial. The results are shown in Table 4, where column (1) reports the results for the full sample including all categories of issuers. We found that the coefficient of the variable of interest for government bonds in column (2) is negative and statistically significant, around 7.9 bps. On the other hand, we did not find a statistically significant difference in the bid-ask spread for corporate green bonds, as shown in column (3), although the point estimate is negative. The results for the financial and non-financial subsamples are reported in columns (4) and (5). Overall, only sovereign entities seem to benefit from a lower bid-ask spread. This can be explained by the fact that their reputation can reduce information asymmetries on the use of proceeds for effective green projects (Fatica et al., 2021; Bachelet et al., 2019; Kapraun et al., 2021). These results are consistent with those of Bachelet et al. (2019), who obtained similar results using a direct matching approach.

Table 4. Regression by type of issuers

	Dependent variable: Bid-Ask Spread					
	Measure					
	All Sample	Gov.	Corp.	Corp. Fin.	Corp. Non-Fin.	Energy
	(1)	(2)	(3)	(4)	(5)	(6)
Green	-0.043**	-0.079***	-0.028	-0.034	-0.035	-0.072**
	(0.019)	(0.025)	(0.029)	(0.047)	(0.042)	(0.035)
Maturity	0.016***	0.019***	0.015***	0.034***	0.013***	0.017***
	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.002)
Amount	-0.046**	-0.063***	0.001	0.024**	-0.076*	-0.017
	(0.018)	(0.018)	(0.012)	(0.011)	(0.041)	(0.031)
Bond FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X
Issuer FE	X	X	X	X	X	X
Green Bonds	220	113	107	38	69	51
Observations	86,057	49,729	36,328	18,738	17,590	14,156
R^2	0.692	0.647	0.782	0.739	0.853	0.890
Adjusted R^2	0.691	0.646	0.781	0.736	0.852	0.889

Notes: The table reports the regression results of equation 1 for different sample of issuers. Standard Errors are clustered at the issuer level. *p<0.1; **p<0.05; ***p<0.01.

Next, we took a closer look at the corporate bonds issued by the corporations by splitting the sample by industry. Column (6) reports the results for the energy sector. We found a significant difference in liquidity between green bonds issued by companies in the energy sector, with a bid-ask spread of around 7.2 bps lower than comparable conventional bonds.

On the other hand, we found that the effect of the green dummy on the average bid-ask spread is not statistically significant for green bonds issued by banks and other financial companies, and for other non-financial companies (results are available upon request). This may be due to the fact that issuers from the energy sector are considered as more credible in terms of the greater impact of their proceeds. To conclude, we partially reject hypothesis 2 since the result at the aggregate level is mostly driven by sovereigns and companies in the energy sector.

We tested whether the credibility of the green label matters (hypothesis 3) by replacing the green dummy with a categorical variable equal to 1 if the green bond is self-labelled, 2 if the green bond is CBI-aligned, 3 if the green bond is CBI Certified and 0 otherwise. Column (1) of Table 5 shows the results for the full sample. We found that the liquidity greenium is negative and statistically significant only for certified bonds (around 21 bps). On the other hand, the coefficient is significantly different from zero for aligned and self-labelled bonds. Columns (2) and (3) report the results for government and corporate sub-samples, respectively. It appears that green bonds issued by governments are more liquid than their conventional counterparts, whether certified or aligned. However, the liquidity premium is almost three times higher for certified bonds than for aligned bonds. Indeed, the latter benefit from a lower bid-ask spread of around 20 bps compared to aligned green bonds (around 7.4 bps). What is more interesting is that corporate issuers benefit from a liquidity greenium, of around 37 bps, only if the bond is CBI Certified. For self-labelled bonds, the green dummy has no effect on the bid-ask spread for either sub-sample. This suggests that the credibility of the issuer's commitment is extremely important for the existence of a liquidity premium. Thus, we do not reject hypothesis 3 even though we acknowledge that our findings may be influenced by the small sample size. For this reason, in Section 6.2 we conducted a robustness analysis of our results, by estimating model 2 on a larger data set of bonds using an alternative measure of liquidity (Zero Trading Days) that can be calculated directly from quoted prices in the absence of bid and ask prices. We found that the results are robust for this larger sample.

Table 5. Regression by type of bond

	Dependent variable: Bid-Ask Spread		
		Measure	
	All Sample	Gov.	Corp.
	(1)	(2)	(3)
Self-Labelled	-0.011	-0.008	0.019
	(0.024)	(0.070)	(0.033)
CBI Aligned	-0.033	-0.074^{***}	-0.013
	(0.023)	(0.028)	(0.031)
CBI Certified	-0.215^{***}	-0.207^{***}	-0.379^{***}
	(0.054)	(0.077)	(0.072)
Maturity	0.016^{***}	0.019^{***}	0.014^{***}
	(0.003)	(0.003)	(0.004)
Amount	-0.046^{**}	-0.064^{***}	0.001
	(0.018)	(0.018)	(0.012)
Bond FE	X	X	X
Time FE	X	X	X
Issuer FE	X	X	X
Green Bonds	220	113	107
Observations	86,057	49,729	36,328
R^2	0.692	0.647	0.783
Adjusted R^2	0.692	0.646	0.782

Notes: The table reports the regression results of equation 2, which formally tests the role of certification/alignment of green bonds to international standards (CBI). Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

Next, we tested hypothesis 4, whether the company' ESG and environmental reputation has an impact on the bid-ask spread. To do so, we added a dummy variable *ScoreTop*, which is equal to 1 if the score is greater than or equal to 75, which is considered by Refinitiv as a threshold if a firm is to be considered as a 'leader' in the ESG profile. We report the results for the full corporate sample in column (1) of Table 6. Column (2) shows the results of the baseline model estimated for the sub-sample of companies for which Refinitiv provides an ESG score, and thus an environmental score. The results for the extended model are shown in columns (3)-(6). Interestingly, in contrast to the findings reported in the baseline specification for corporate bonds, we find that if we restrict our sample to companies with an ESG score, the green bond dummy is negative and significant, resulting in a liquidity greenium of around 12 bps. On the other hand, we find that green bonds issued by firms with a good environmental reputation benefit from a lower bid-ask spread of around 18 bps, and the effect on the bid-ask spread is not explained by the score itself. In conclusion, firms that certify their commitment to use the proceeds for green projects or that enjoy a high environmental reputation may also benefit from higher liquidity in the secondary market. Thus, we do not reject hypothesis 4. Kapraun et al. (2021) found similar results with respect to the yield premium.

Table 6. ESG and environmental performance of the issuer

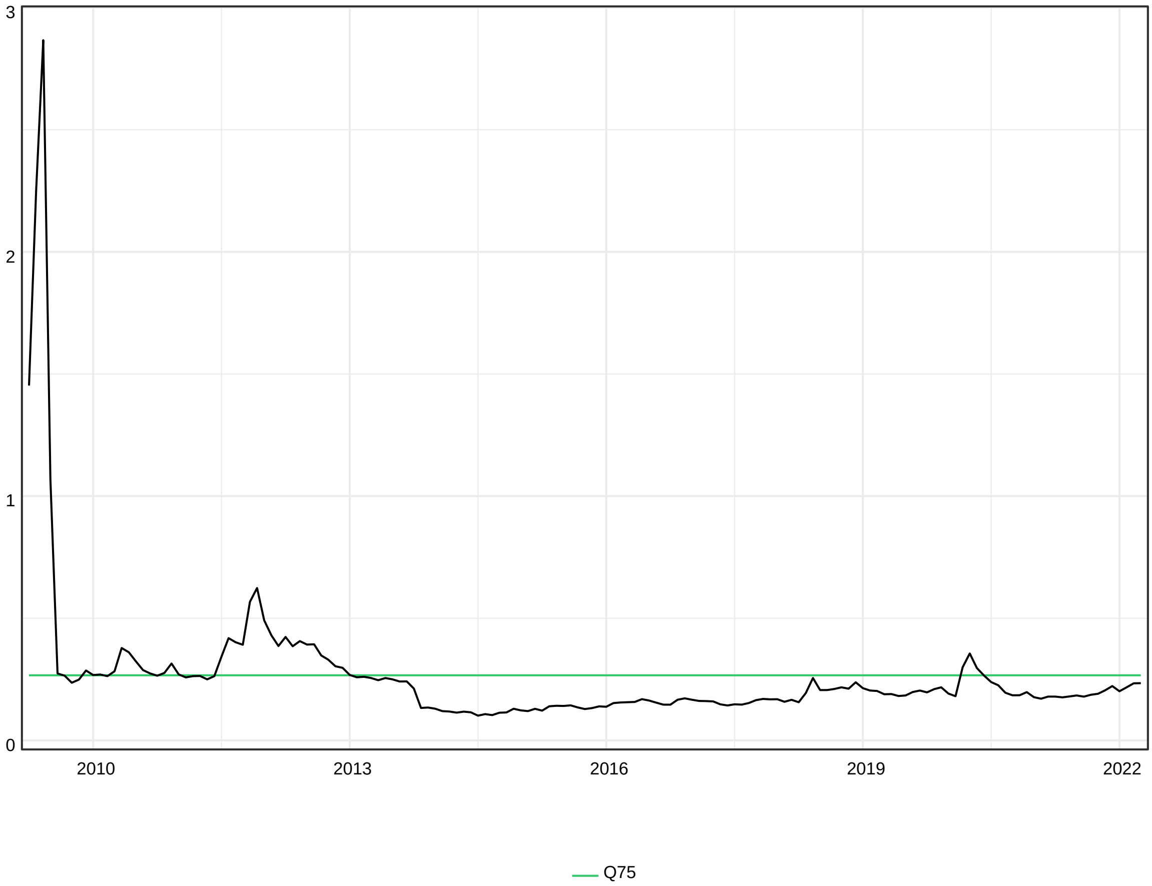
	Dependent variable: Bid-Ask Spread					
	Measure					
	Corp.	Score	ESG Score	ESG Score	Env. Score	Env. Score
	(1)	(2)	(3)	(4)	(5)	(6)
Green	-0.028	-0.128**	-0.150**	-0.113	-0.025	0.0004
	(0.029)	(0.050)	(0.073)	(0.072)	(0.077)	(0.084)
ScoreTop				0.084***		0.121***
				(0.022)		(0.041)
Maturity	0.015***	0.016***	0.016***	0.016***	0.016***	0.016***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Amount	0.001	-0.025	-0.026	-0.027	-0.027	-0.026
	(0.012)	(0.019)	(0.019)	(0.020)	(0.019)	(0.020)
Green*ScoreTop			0.038	-0.028	-0.189**	-0.235***
			(0.073)	(0.072)	(0.080)	(0.089)
Bond FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X
Issuer FE	X	X	X	X	X	X
Green Bonds	107	29	29	29	29	29
Observations	36,328	7,867	7,867	7,867	7,867	7,867
R^2	0.782	0.770	0.770	0.772	0.771	0.773
Adjusted R^2	0.781	0.764	0.764	0.766	0.766	0.768

Notes: The table reports the regression results of equation 3, which formally tests the role of the ESG reputation of the issuer. Column (1) corresponds to column (3) in Table 4. Column (2) shows the estimate restricted to the sample of firms with available scores. In columns (3) to (6), we use different scores (ESG vs Environmental) to test the role of the reputation of the issuer. Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

5.2 Time Series evidence on the liquidity of green bonds

First, we investigated the liquidity of green bonds during periods of aggregate liquidity stress. We measured the illiquidity of the market as a whole using the average bid-ask spread of the sample weighted by the market value of the bonds. Our liquidity proxy is shown in Figure 3.

Figure 3. Illiquidity of the market



Notes: This figure shows the proxy for market illiquidity used in our analysis. The proxy is calculated as the average bid-ask spread of the sample, weighted by the market value of the bonds. Periods of higher market illiquidity are defined when the proxy is above the 75th percentile of its empirical distribution.

Table 7 shows the results obtained by adding the liquidity stress to the baseline specification. We found that the interaction term between the green dummy and the illiquidity indicator is negative, i.e. the liquidity greenium increases in periods of stress, but is not statistically significant. The results for the government and corporate sub-samples are shown in the same table. For government green bonds, the previous findings are confirmed. However, when we focused on corporate green bonds, we found evidence of a higher liquidity premium in periods of market illiquidity. We interpret these results as follows. In periods of market stress, corporate green bonds attract more investor demand, leading to an improvement in the liquidity premium of these bonds relative to conventional bonds. This result does not hold for sovereign issuers, perhaps because the sovereign bonds per se are perceived by investors as a safe haven in times of market turbulence. In conclusion, we do not formally reject hypothesis 5.

Table 7. Liquidity stress

	Dependent variable: Bid-Ask Spread		
		Measure	
	All Sample	Gov.	Corp.
	(1)	(2)	(3)
Green	-0.041	-0.077***	-0.030
	(0.062)	(0.024)	(0.062)
Maturity	0.016***	0.019***	0.015***
	(0.003)	(0.003)	(0.003)
Amount	-0.045***	-0.062***	0.001
	(0.012)	(0.017)	(0.012)
Green*StressQ75	-0.016	0.014	-0.085*
	(0.050)	(0.087)	(0.050)
Bond FE	X	X	X
Time FE	X	X	X
Issuer FE	X	X	X
Green Bonds	107	0	107
Observations	86,057	49,729	36,328
R^2	0.696	0.654	0.785
Adjusted R^2	0.695	0.653	0.784

Notes: The table reports the regression results of equation 4 where we investigate the liquidity of green bonds in times of aggregate liquidity stress. Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

Next, we investigated the effect of the announcement of the Monetary Policy Strategy Review on 8 July 2021 on the liquidity of corporate green bonds (hypothesis 6). The period after this date corresponds to the *Post* dummy in our regression. To do this, we constructed weekly time series for the bid-ask spreads, and we only kept the observations between March 2021 and September 2021. Table 8 presents the results. Column (1) shows the results for the full sample and column (2) the results for the sub-sample of ECB-eligible bonds. As expected, in the full sample the effect of the Post dummy is not significantly different from zero. However, the results in column (2) suggest that after the announcement the ECB-eligible green bonds benefited from a lower bid-ask spread when compared to ECB-eligible conventional bonds. The findings are in line with Eliet-Doillet and Maino (2022), who, using a similar approach, found that the ECB announcement had a significant impact on the pricing and issuance of green bonds. In particular, the authors found that after the announcement the yield to maturity of ECB-eligible green bonds fell relative to ECB-eligible conventional bonds. We therefore formally accept hypothesis 6.

Table 8. Effect of green monetary policy for corporate green bonds

	Dependent variable: Bid-Ask Spread	
	Measure	
	All	ECB Eligible
	(1)	(2)
Maturity	0.021***	0.022***
	(0.002)	(0.004)
Amount	-0.010	-0.021**
	(0.012)	(0.010)
Green*Post	-0.013	-0.121***
	(0.031)	(0.025)
Bond FE	X	X
Issuer FE	X	X
Time FE	X	X
Green Bonds	83	23
Observations	17,189	5,213
R^2	0.836	0.876
Adjusted R^2	0.835	0.874

Notes: The table reports the regression results of equation 5 where we investigate the effect of the announcement of the Monetary Policy Strategy Review announcement on 8 July 2021, on the liquidity of corporate green bonds. Column (2) reports the estimate restricted to the sample of bonds that is eligible as ECB collateral. Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

Finally, we tested whether the issuance of a green bond has some spillover effects on the liquidity of the conventional bonds issued by the same issuer (hypothesis 7). We focused on the sub-sample of issuers with at least two bond issues. For each issuer, we considered only the conventional bonds with a time series of the bid-ask spread covering a window of 3 months before and 3 months after the announcement date of the green bond so that we had a balanced panel. Table 9 shows the results. If we look at the first issues of green bonds, we find a reduction in the bid-ask spread for government and supranational bonds (around 6 bps). This implies that the bid-ask spread of a sovereign conventional bond decreases after the announcement of a green bond issue. The first green bond is important because of its signalling effect of commitment to the environment. Indeed, the literature finds a significant positive reaction of the equity valuations (Flammer, 2021) and of the CDS spread (Ahn et al., 2022). For corporates, we found a reduction in the bid-ask spread only after the second green bond emission (around 2 bps). We interpreted this result through the lens of the previous results on the role of certification and reputation on green bond liquidity (hypothesis 3 and 4). For green bond issuers to enjoy a liquidity premium on conventional bonds, the company must be perceived as credible by the market. Here credibility is enhanced by experience, which in this case is proxied by multiple green bond issues. We ran robustness checks for different windows up to 5 months around the issue date, and concluded that the findings for corporate bonds are robust. For government bonds, the coefficient was always negative and significant in most cases (except for 2 and 5 months). To conclude, we accept hypothesis 7, which states that there is a positive liquidity spillover to conventional bonds issued by green bond issuers, even if this result holds for sovereign and 'seasoned' corporate green bond issuers.

Table 9. Spillover effect to conventional bonds after 3 Months

	Dependent variable: Bid-Ask Spread					
	Measure					
	All Sample	Gov.	Corp.	All Sample	Gov.	Corp.
	(1)	(2)	(3)	(4)	(5)	(6)
Green	-0.014	-0.063**	0.025	-0.005	0.006	-0.022***
	(0.018)	(0.032)	(0.021)	(0.009)	(0.013)	(0.003)
Maturity	0.024***	0.015	0.026***	0.023***	0.024	0.024***
	(0.004)	(0.013)	(0.004)	(0.006)	(0.015)	(0.006)
Amount	-0.023	-0.075	0.018	-0.068	-0.182***	0.009***
	(0.036)	(0.061)	(0.028)	(0.059)	(0.067)	(0.003)
Bond FE	X	X	X	X	X	X
Issuer FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X
Green Bonds	0	0	0	0	0	0
Observations	8,856	3,861	4,995	7,317	3,024	4,293
R^2	0.773	0.649	0.869	0.693	0.674	0.856
Adjusted R^2	0.761	0.615	0.860	0.681	0.652	0.851

Note: The table reports the regression results of equation 6 where we investigate the existence of some spillover effects on the liquidity of the conventional bonds following the announcement of a green bond issue. Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

6. Robustness

In this section we present two robustness checks for the main results presented in Table 4 and Table 5. In particular, as discussed above, due to the lack of bid-ask spreads and ratings for all green bond issuers, the final data set used to test our empirical hypotheses was much smaller than the initial set of bonds. In the following sections, we attempt to circumvent this data constraint to expand our estimation data set and test the robustness of our previous findings.

6.1 Bond and issuer rating

In this robustness analysis, we tested our hypotheses 1, 2 and 3 using the issuer rating when the bond rating is missing. Under this assumption, our final sample was made up of 2 875 bonds, of which are 336 were green, compared to the data set of our baseline specification, which consisted of 1 764 bonds, of which 220 were green. Table 10 shows the results for the full sample (hypothesis 1), and across for different types of issuers (hypothesis 2). In the baseline regression in column (1) of Table 10 it can be seen that the liquidity premium is not significant for the full sample, although the coefficient is still negative. For green bonds issued by governments and supranational entities (column (2)), we again observed a significantly lower bid-ask spread, by around 10 bps on average. Columns (4) to (5) confirm our previous finding regarding the lack of a liquidity premium for green bonds issued by corporations, both financial and non-financial. Table 10 shows the results across for different corporate sectors. Nevertheless, we found a reduction of around 7 bps in the bid-ask spread for the green bonds issued by the energy sector, compared to similar conventional bonds.

Table 10. Regression by type of issuers: robustness check using issuer rating

	Dependent variable: Bid-Ask Spread					
	Measure					
	All Sample	Gov.	Corp.	Corp. Fin.	Corp. Non-Fin.	Energy
	(1)	(2)	(3)	(4)	(5)	(6)
Green	-0.035	-0.107***	0.017	0.006	-0.001	-0.066*
	(0.025)	(0.034)	(0.025)	(0.038)	(0.030)	(0.034)
Maturity	0.017***	0.018***	0.017***	0.037***	0.014***	0.017***
	(0.002)	(0.003)	(0.004)	(0.004)	(0.004)	(0.002)
Amount	-0.037**	-0.051***	-0.003	0.011	-0.048	-0.020
	(0.016)	(0.015)	(0.012)	(0.007)	(0.032)	(0.030)
Bond FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X
Issuer FE	X	X	X	X	X	X
Green Bonds	336	136	200	66	134	57
Observations	132,074	77,962	54,112	29,821	24,291	14,897
R^2	0.665	0.632	0.736	0.715	0.813	0.878
Adjusted R^2	0.664	0.631	0.735	0.713	0.812	0.876

Notes: The table reports the regression results of equation 6 where we investigate the existence of some spillover effects on the liquidity of the conventional bonds following the announcement of a green bond issue. Standard Errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

Finally, we used the new sample to test our hypothesis on the role of the certification (hypothesis 3). In this case, the number of certified and aligned bonds increases to 24 and 100 for sovereign issuers and 6 and 165 for corporate issuers. The results in Table 11 corroborate our finding that only certified and aligned green bonds benefit from a liquidity premium. Indeed, the coefficients of interest are negative and significant even though the magnitude is lower, especially for the corporate bond (around 26bps).

Table 11. Regression by type of bonds: robustness check using issuer rating

	Dependent variable: Bid-Ask Spread		
		Measure	
	All Sample	Gov.	Corp.
	(1)	(2)	(3)
Self-Labeled	-0.013	-0.031	0.019
	(0.024)	(0.067)	(0.032)
CBI Aligned	-0.028	-0.108***	0.030
	(0.027)	(0.036)	(0.027)
CBI Certified	-0.188***	-0.171***	-0.258***
	(0.044)	(0.051)	(0.091)
Maturity	0.018***	0.018***	0.017***
	(0.002)	(0.003)	(0.004)
Amount	-0.037**	-0.052***	-0.003
	(0.016)	(0.015)	(0.012)
Bond FE	X	X	X
Time FE	X	X	X
Issuer FE	X	X	X
Green Bonds	336	136	200
Observations	132,074	77,962	54,112
R^2	0.665	0.632	0.737
Adjusted R^2	0.664	0.631	0.735

Notes: The table reports the regression results of equation 2, which formally tests the role of certification/alignment of green bonds to international standards (CBI). Compared to Table 5, we expanded the sample of bonds in our analysis by using the issuer rating when the bond rating is missing. Standard errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

6.2 Zero Trading Days

In this section we use the Zero Trading Days measure from Lesmond, Ogden, and Trzcinka Lesmond et al. (1999) as the dependent variable. We calculate the Zero Trading Days at daily frequency as

$$ZTD_{b,t,i} = \frac{N_{b,t,i}^{ZTD}}{N_t} \tag{8}$$

where $N_{b,t,i}^{ZTD}$ is the number of days in the previous month on which bond *b*, listed at time *t* and issued by issuer *i* has zero return, and N_t is the number of trading days in the previous month. Thus, we take the monthly average. Like the bid-ask spread, the zero trading day estimator is an indicator of the illiquidity of a bond and it is used as a proxy for transaction costs. Counting the number of days on which a bond is not traded over a given period, gives a sense of how frequently the bond trades and how easy it is to buy or sell. The advantage of this measure is that it is calculated using only time series daily price data rather than bid and ask prices, which can be more complex to interpret and difficult to retrieve. Indeed, the number of bonds with available data on price was 14 863, of which 1 163 were green. After excluding the bonds for which the other main characteristics are not available and after matching the issuer, we were left with 2 345 bonds, of which 237 were green. In this case, we lost about 60 % of the bonds because of missing rating information. Our final sample in this case was larger than the sample used in our baseline regression, essentially because we were able to include additional conventional bonds for the same green bond issuers. To mitigate the effects of outliers, we windsorised the time series of returns.

Table 12 presents the results for the full sample and for different types of issuers. Column (1) confirms our previous finding on the existence of a liquidity premium for the full sample. In column (2), we again find that most of the premium is explained by the government issuers. The green bond label reduces the number of Zero Trading Days by 4 % for sovereign issuers, compared to almost 1 % for corporate issuers. Interestingly, for the corporate sector, most of the effect comes from the financial sector (almost 3 % lower *ZTD*). Looking at the results for the corporate sector, we found that only the green bonds issued by the banks benefited from such a reduction. Finally, Table 13 presents the results for different types of green bonds. In this case, the number of aligned bonds increases to 89 and 86 for sovereign and corporate issuers respectively, while the number of certified bonds is the same. In both the full sample and the government sub-sample, we find a liquidity greenium only for aligned bonds. For the corporates the coefficient is always negative but significant only for the certified bonds, confirming our previous findings. In conclusion, our baseline results are broadly confirmed in these extended data sets[8].

[8] Additionally, we carried out a robustness test using the issuer rating when the bond rating is missing and the *ZTD* as the dependent variable. The number of green bonds in this case increases to 562. The results are substantially confirmed and they are available upon request.

Table 12. Regression by type of issuers: robustness check using Zero Trading Days

	Dependent variable: Zero Trading Days					
	Measure					
	All Sample	Gov.	Corp.	Corp. Fin.	Corp. Non Fin.	Energy
	(1)	(2)	(3)	(4)	(5)	(6)
Green	-0.027***	-0.040***	-0.011*	-0.029**	-0.005	-0.005
	(0.010)	(0.015)	(0.006)	(0.014)	(0.006)	(0.004)
Maturity	-0.00002	0.001	-0.0005	-0.003	-0.0003	-0.0002
	(0.0004)	(0.001)	(0.0004)	(0.002)	(0.0004)	(0.0005)
Amount	-0.017***	-0.018***	-0.010***	-0.008***	-0.016	-0.003
	(0.005)	(0.006)	(0.003)	(0.003)	(0.010)	(0.002)
Bond FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X
Issuer FE	X	X	X	X	X	X
Green Bonds	237	115	122	42	80	59
Observations	124,547	62,733	61,814	27,051	34,763	26,176
R^2	0.463	0.482	0.502	0.499	0.549	0.620
Adjusted R^2	0.462	0.480	0.500	0.495	0.547	0.617

Notes: The table reports the regression results of equation 1 for a different sample of issuers. Compared to Table 4, we expanded the sample of bonds in our analysis by using ZTD as dependent variable. Standard errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

Table 13. Regression by type of bonds: robustness check using Zero Trading Days

	Dependent variable: Zero Trading Days		
		Measure	
	All Sample	Gov.	Corp.
	(1)	(2)	(3)
Self-Labeled	-0.010	-0.024*	-0.0004
	(0.012)	(0.013)	(0.015)
CBI Aligned	-0.022***	-0.031***	-0.008
	(0.008)	(0.009)	(0.006)
CBI Certified	-0.115	-0.142	-0.085***
	(0.098)	(0.149)	(0.015)
Maturity	-0.00000	0.001	-0.001
	(0.0004)	(0.001)	(0.0004)
Amount	-0.018***	-0.018***	-0.009***
	(0.005)	(0.006)	(0.003)
Bond FE	X	X	X
Time FE	X	X	X
Issuer FE	X	X	X
Green Bonds	237	115	122
Observations	124,547	62,733	61,814
R^2	0.464	0.483	0.503
Adjusted R^2	0.463	0.482	0.501

Notes: The table reports the regression results of equation 2, which formally tests the role of certification/alignment of green bonds to international standards (CBI). Compared to Table 5, we expanded the sample of bonds in our analysis by using ZTD as a proxy for liquidity. Standard errors are clustered at the issuer level. ∗p<0.1; ∗∗p<0.05; ∗∗∗p<0.01.

7. Conclusions

Understanding the liquidity characteristics of green bonds is extremely important. However, the literature has so far only partially investigated this issue, with mixed evidence. In this paper, we investigated the relationship between liquidity and green bond label using a sample of green bonds issued globally. Our purpose was to determine whether green bonds offer investors enhanced liquidity relative to conventional bonds with similar characteristics. To identify possible differences in liquidity, we estimated a fixed effects model that allows for time-invariant heterogeneity of bonds and issuers and global time-varying unobservable factors that affect the market. After controlling for relevant bond and issuer characteristics, our findings suggest that green bonds are more liquid than comparable ordinary bonds. However, the existence of a difference in the liquidity premium varies considerably across issuer and bond types. The difference is large and statistically significant for bonds issued by governments or supranationals, while it is not significantly different from zero for corporates, unless the company operates in the energy sector. Lower liquidity for corporate issuers generally requires a certification of the quality of the issue or a good environmental performance, which protects the investors against greenwashing. Thus, companies that certify their commitment to use the proceeds for green projects or enjoy a strong environmental reputation can also benefit from higher liquidity in the secondary market.

In the time series dimension, we investigated the liquidity of green bonds during periods of higher market illiquidity and provided evidence on the importance of the green label during periods of market stress. We found that the liquidity conditions of corporate green bonds improve relative to conventional bonds during periods of market turbulence, such as the recent Covid-19 crisis. This may suggest that green bonds are perceived as a safe asset that attracts investor demand in times of stressed markets, and it could be relevant for banks in conducting liquidity stress testing as part of their liquidity risk management. Our results also revealed that policy changes, such as the ECB’s change in its monetary policy strategy, can affect the liquidity of green bonds. Indeed, the liquidity of ECB-eligible green bonds improves relative to similar conventional bonds, possibly because they become more attractive to banks with access to ECB funding. Finally, we found that the liquidity of conventional bonds issued by green bond issuers improved significantly in the one-year period following the green announcement. This spillover effect could be attributed to the fact that the issuance is perceived as a signal of commitment to sustainability and therefore the issuer benefits from higher demand by investors, thus improving its liquidity conditions.

Overall, our results show that green bonds are not only a fundamental tool for the development of sustainable finance and the achievement of the EU goals, but they could also be a way for investors to improve the liquidity of their portfolios. This suggests that bank liquidity indicators may need to capture the different degree of liquidity among bonds, depending on their ‘greenness’. Our findings also support the need for uniform standards for the market, such as the forthcoming EU Green Bond Standard.

Compliance with Ethical Standards:

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