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Pricing of green bonds: drivers and dynamics of the greenium

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Abstract

The green bond market has increased rapidly in recent years amid growing concerns about climate change and wider environmental issues. However, whether green bonds provide cheaper funding to issuers by trading at a premium, so-called greenium, is still an open discussion. This paper provides evidence that a key factor explaining the greenium is the credibility of a green bond itself or that of its issuer. We define credible green bonds as those which have been under external review. Credible issuers are either firms in green sectors or banks signed up to UNEP FI. Another important factor is investors' demand as the greenium becomes more statistically and economically significant over time. This is potentially driven by increased climate concerns as the green bond market follows a similar trend to that observed in ESG/green equity and investment fund sectors. To run our analysis, we construct a database of daily pricing data on closely matched green and non-green bonds of the same issuer in the euro area from 2016 to 2021. We then use Securities Holdings Statistics by Sector (SHSS) to analyse investors' demand for green bonds.

JEL classification: G12, G14, Q50, A56

Key words: climate change; sustainable finance; impact investing; corporate sustainability

1 Non-technical summary

Green bonds are sustainable finance instruments that aim at financing environmentally sustainable projects and the transition to a low-carbon economy. The green bond market has shown fast growth since 2015 and reached USD 1 tn of cumulative issuance in 2020. Yet, it still represents a small share of the overall bond market. To assure continuous growth of the green bond market and availability of financial resources for the green transition, green bonds have to gain investors' trust. The presence of a premium for green bonds, i.e. a greenium, can point to investors' confidence and preferences for these instruments.

In this paper, we investigate if the spread between green and conventional bonds issued by euro area entities is negative, thus green bonds trade at a greenium. As the range of spreads across pairs of matched green and non-green bonds is large both in the cross-sectional and time dimension (Fig. 2), we analyse which factors explain the greenium in both dimensions.

Figure 1: Distribution of spreads between matched green and conventional bonds. The green box shows the interquartile range between the 25th and 75th percentile.

In the absence of a common definition and a standard for green bonds[1], committed investors

[1]EU Green Bond Standard (EU GBS) should become such a standard once adopted

need to make additional efforts to identify green bonds with a positive impact on the environment and/or the transition. In this case, they may also be willing to pay a premium to hold a greener green bond. Thus, we first analyse if investors prefer greener green bonds. The latter are defined either by bond credibility, i.e. bonds with external review (e.g., certification, second-party opinion), or by issuers' credibility, i.e., issuers in green sectors or issuers committed to environmental programs, e.g. the United Nations Environmental Program Finance Initiative (UNEP FI).

Next, we analyse if the greenium changes over time and what explains its dynamics. We explore if the greenium is driven by higher investor demand and if it is part of a common trend in ESG/green assets documented by, e.g., Pastor et al. (2021) and van der Beck (2021). These studies show over-performance of green/ESG equity securities that Pastor et al. (2021) explain by higher investor demand due to rising climate concerns.

We run our analysis on green bonds issued in the euro area from 2016 to 2021, using a definition of green bonds provided by the ICMA Green Bond Principles (GBP) [2] and available in Bloomberg. We construct a control group of conventional bonds as similar to the sample of green bonds as possible, using a k-prototypes matching algorithm. We further distinguish the quality of greenness depending on whether a green bond has a third-party external review, as the latter is only optional in ICMA GBP. Finally, we complement the market data on green bonds with data on holdings of green bonds by investors at the sector level using Securities Holdings Statistics by Sector (SHSS).

Our paper presents three main findings. First, on the full sample, we find a greenium of about 4bps, though significant only at 10%. Second, this greenium is fully explained by green bonds with higher greenness. We conclude that credibility matters, both at a bond and an issuer level: Green bonds with external review have a highly statistically significant greenium of 5.3bps. Green bonds issued by green firms and by UNEP FI banks also trade at a more economically and statistically significant greenium of 22.2bps and 17.38 bps, respectively. Third, we find that the greenium evolves over time and becomes more economically and statistically significant,

[2] The framework sets up four main criteria of voluntary best practices according to which bonds are classified as green bonds. First, a bond is considered green if the *Use of Proceeds* principle is satisfied, i.e. the issuer uses the bond proceeds to finance eligible green projects. Second, the *Process for Project Evaluation and Selection* principle is satisfied if the issuer clearly communicates what the objectives of the green project are. The third principle is the *Management of Proceeds* principle which requires the bond proceeds to be clearly managed and tracked within the company's financial structure and the *Reporting* principle demands companies to report on their green bond use of proceeds in their final report.

however, only for green bonds issued by banks. Green bonds of alternative energy firms trade at a greenium over the entire period. Finally, we show that the greenium on green bonds issued by banks is driven by an increased demand from retail investors.

This paper contributes to an important policy debate about the European Union Green Bond Standard (EUGBS). In particular, it exposes the need for a regulatory standard that will provide a clear definition of green bonds and requirements to assure that proceeds raised from the issuance of green bonds positively contribute to the transition. Institutional investors may not have strong incentives to monitor environmental performance of green bonds while retail investors may not have the capacity and knowledge to so. Thus a regulatory standard is key to channel investments into projects fostering the transition. Furthermore, only a unique standard can help avoid investors' confusion, loss of confidence and potential runs even on highly credible green bonds.

2 Introduction

Green bonds are sustainable finance instruments that aim at financing environmentally sustainable projects and the transition to a low-carbon economy. The green bond market has shown fast growth since 2015 and reached USD 1 tn of cumulative issuance in 2020, however, it still represents a small share of the overall bond market. To assure continuous growth of the green bond market and availability of financing for the transition, green bonds have to gain investors' trust. Presence of a premium for green bonds, i.e. a greenium, can point to investors' confidence and preferences for these instruments.

In this paper, we investigate if the spread between green and conventional bonds issued by euro area entities is negative and thus green bonds trade at a greenium. Figure 2 shows the difference in option-adjusted spreads (OAS) between matched green and non-green bonds of the same issuer. This descriptive statistic shows that there is large heterogeneity between pairs as the the range of differences in spreads is large both in the cross-sectional and time dimension. Therefore, we analyse which factors explain the greenium in the cross-section and over time.

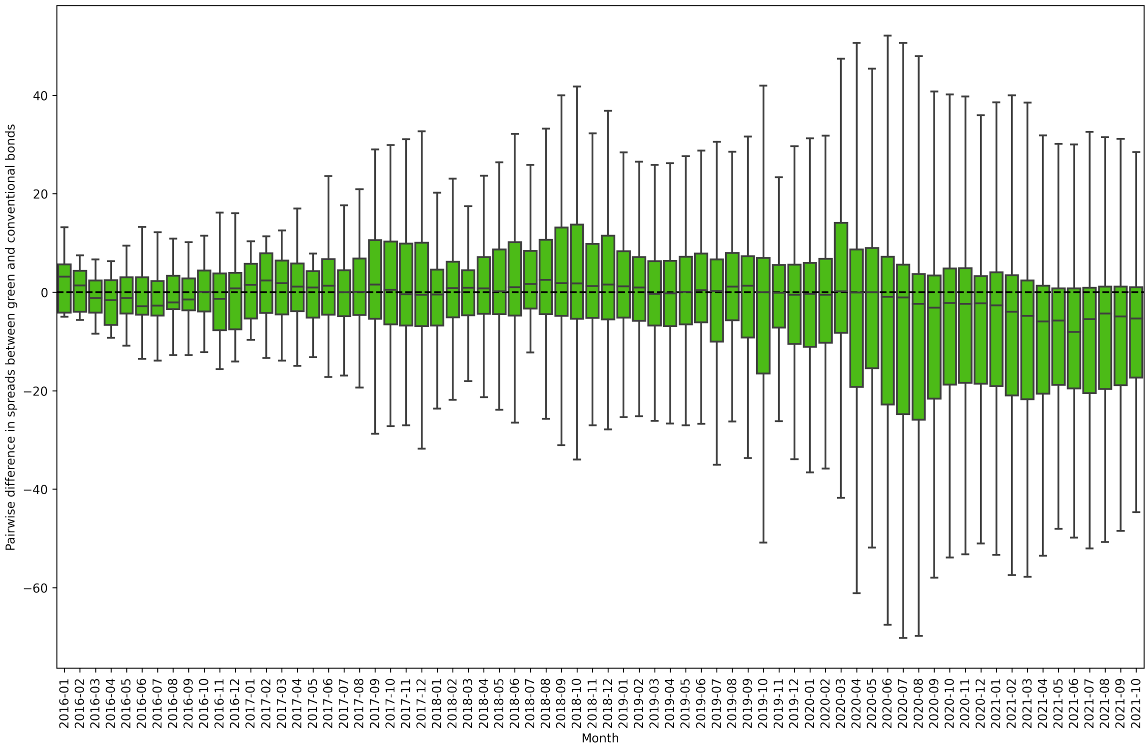

Figure 2: Distribution of spreads between matched green and conventional bonds. Green box corresponds to the range between 25th and 75th percentile.

In the absence of a common definition and standard for green bonds, committed investors need to make additional efforts to identify green bonds with a positive impact on the environment and/or the transition. In this case, they may also be willing to pay a premium to hold a greener green bond. Thus, we start our analysis by studying if investors prefer greener green bonds. The latter are defined either by bond credibility, i.e. bonds with external review (e.g., certification, second-party opinion), or by issuer's credibility, i.e., issuers committed to environmental programs or issuers in green sectors, such as alternative energy.

Next, we analyse if the greenium changes over time and what explains its dynamics. We explore if the greenium is driven by higher investor demand, and also if this is part of a common trend in ESG/green assets documented by, e.g., Pastor et al. (2021) and van der Beck (2021). These studies show over-performance of green/ESG equity securities that Pastor et al. (2021) explain by higher investor demand due to rising climate concerns.

To run the analysis, we construct a database covering all green bonds issued in the euro area from 2016 to 2021 using several data sets. In our study, we use a definition of green bonds provided by the ICMA Green Bond Principles (GBP), used by Bloomberg and overall the most widely used definition in the market. Ehler and Packer (2017) estimate that Bloomberg covers about 80% of the green bond market in 2017. We obtain data on green bonds from Bloomberg that also allow us to distinguish the quality of greenness depending on whether a green bond has external review or not. It is important to note that ICMA GBP only recommend external review but do not require it. We complement the data on green bonds with market data on prices and bond characteristics from Bloomberg and the ECB's Centralised Securities Database (CSDB). Finally, we use Securities Holdings Statistics by Sector (SHSS) to obtain information on holdings of green bonds by investor type at the sector level.

We perform our analysis on a panel data set with daily data on option-adjusted spreads (OAS). For this, we use a sample of green and conventional bonds to study whether green bonds systematically trade at lower spreads than conventional bonds. We include a green dummy variable equal to one if a bond is green and zero otherwise. To cleanly isolate the effect of this green bond indicator variable on bond spreads, we construct a control group of conventional bonds that are as similar to the sample of green bonds as possible. We obtain this sample of green and conventional bonds by using a k-prototypes matching algorithm which matches exactly one conventional bond of the same issuer with the most similar characteristics to each green bond. Starting from the entire universe of all 1400 green bonds issued until October 2021, we find an appropriate conventional bond match for 124 green bonds. We complement this sample of 248 total bonds (or 124 bond pairs) with daily data on option-adjusted spreads from 2016 to 2021.

On the sample of matched green and non-green bonds, we test several hypotheses in a bond-date panel setup. We first explain the OAS of a bond by main factors such as credit risk, liquidity premium, maturity, risk-aversion and bond intrinsic characteristics. Then we add a green dummy to the regression to test if being green carries additional information.

Hypothesis 1: Green bonds trade at a greenium on the full sample over the period 2016-2021.

Given significant heterogeneity in spreads between green and non-green bonds, the following three hypotheses explore the role of credibility on the size of greenium. We define credibility in three ways. First, bond-level credibility is related to green bonds with external review. External review which can be in the form of a second-party opinion, verification or certification, is optional under the ICMA GBP, but it is also costly and time-consuming for the issuer. Therefore, if an issuer chooses to obtain external review for its green bonds, this signals a stronger commitment to investors.

Hypothesis 2: Only green bonds with external review trade at a greenium.

Second, we define credibility at the issuer level. Green firms, e.g.,those operating in the alternative energy sector, may be considered more credible as it is easy to grasp their positive contribution on the transition.

Hypothesis 3: Only green bonds issued by green firms trade at a greenium.

Banks are major issuers of green bonds in the market and in our sample. However, banks and financial institutions stay on the sidelines as they play an intermediary role. They do not emit themselves but they decide which firms and sectors to finance. A way to assess banks' credibility as issuers of green bonds is to look at their public commitments. To do this, we follow Fatica et al. (2021) and Delis et al. (2021), and choose the United Nations Environment Program Finance initiative (UNEP FI), a partnership established between United Nations Environment Program and financial sector. This partnership seeks to encourage financial institutions to better implement sustainability principles at all levels of operations. Banks that sign the UNEP FI partnership publicly commit to include sustainability principles in their operations, including investments.

Hypothesis 4: Only green bonds issued by banks engaged in UNEP FI trade at a greenium.

In the next two hypotheses, we explore the time dimension. As documented by recent studies, e.g., Pastor et al. (2021), van der Beck (2021), green and ESG equity over-performed their traditional peers in recent years. Thus we test if this phenomenon is confirmed for green bonds, and the spread between green and non-green bonds has become larger and more statistically significant over time.

Hypothesis 5: The greenium becomes more economically and statistically significant over time.

Finally, we are interested if the trend of a higher greenium is explained by higher investor demand. As climate concerns rise, more investors start investing in green assets, thus driving the demand. To test this hypothesis, we use data on investors' holdings of green and non-green bonds.

Hypothesis 6: The greenium is driven in part by investors' demand

Our analysis provides three main findings. First, on the full sample, we find a greenium of about 4bps, though significant only at 10%. Second, this greenium is fully explained by green bonds with higher greenness. We conclude that credibility matters, both at a bond and an issuer level. Green bonds with external review have a highly statistically significant greenium of 5.3bps. Green bonds issued by green firms and by UNEP FI banks also trade at a more economically and statistically significant greenium of 22bps and 17bps, respectively. Third, we find that the greenium evolves over time and becomes more economically and statistically significant, however, only for green bonds issued by banks. Green bonds of alternative energy firms trade at a greenium over the entire period. Finally, we show that the greenium of green bonds issued by banks is driven by increased demand of retail investors.

Our paper contributes to the literature in several ways. First, we contribute to the debate on the existence of the greenium in secondary markets. Most papers study the greenium in primary markets, and the results are rather mixed: Tang and Zhang (2018), and Flammer (2021) find no greenium in the worldwide corporate green bond sample; Larcker and Watts (2020) document the absence of the greenium in the US municipal bond market, while Ehler and Packer (2017) and Kapraun et al. (2021) find an economically significant greenium of about 20 bps for corporate green bonds. All studies agree that only green bonds with external review exhibit a greenium. They look at various aspects of credibility such as currency and issuer country. More specifically, green bonds issued in EUR and in the European Union trade at a greenium while Chinese green bonds do not (Kapraun et al. (2021)). Fatica et al. (2021) also find that green bonds of UNEP FI financial institutions are issued with a greenium. While cost of funding for companies is defined by bids in primary markets, secondary markets nevertheless have a strong effect on primary markets via the price and liquidity of bonds (Bond et al. (2012)). The literature also studies the greenium in secondary markets and find a large range of results: Zerbib (2019) finds a "small, albeit significant" greenium of 2bps on a heterogeneous sample of bonds; Karpf and Mandel (2017) find a green bond discount, a positive yield differential for green bonds, of about 8bps, while Ehler and Packer (2017) and Kapraun et al. (2021) document that green bonds perform mostly very similarly to conventional bonds. Our second contribution is to analyse the effect of different aspects of credibility on the greenium in secondary markets. To our knowledge, we are the first to do it. Finally, we are also the first to show how the greenium evolves over time, its connection to a larger trend of green assets, and the role of investor demand to explain the greenium.

The remaining paper is structured as follows. Section 3 explains the data we use and the matching algorithm to obtain pairs of green and non-green bonds. Section 4 sets up an econometric specification and hypotheses, and discusses the results. Section 5 places the results in a larger perspective and discusses policy implications of the findings. Section 6 provides the details of robustness tests. Finally, Section 7 concludes.

3 Data

3.1 Identifying green bonds

Generally, green bonds do not differ from conventional bonds except that their proceeds are earmarked to exclusively finance green projects defined by the issuer. In other words, the proceeds from green bonds are earmarked to finance only projects with environmental benefits. However, as there is no global or even regional European definition how to define "environmentally beneficial" projects, different standards are used by market participants. The same applies to green label certification, second-party opinion and verification: various organisations provide services of external review for green bonds with no standardisation across approaches and methodologies.

For this reason, in January 2020, the European Commission announced its plans to introduce a European green bond standard (EUGBS) as part of the European green deal investment plan. The EUGBS is expected to provide a gold standard for green bonds with a unified approach to classification, pre-, post- and annual reporting of the use of proceeds, as well as placing external review providers under under ESMA's direct supervision.

Meanwhile, a widely used classification framework is the International Capital Market Association (ICMA)'s Green Bond Principles. The framework sets up four main criteria of voluntary best practices according to which bonds are classified as green bonds. First, a bond is considered green if the *Use of Proceeds* principle is satisfied. According to ICMA, this is the case if the bond issuer earmarks the bond proceeds to finance eligible green projects [3] which are described in their legal documentation. Second, the *Process for Project Evaluation and Selection* principle is satisfied if the issuer clearly communicates a) what the objectives of the green project are, b) what makes the project eligible and c) what the associated environmental and social risks are. The third principle is the *Management of Proceeds* principle which requires the bond proceeds to be clearly managed and tracked within the company's financial structure, e.g. by creating a sub-account for the proceeds. Finally, the *Reporting* principle is fulfilled if companies report on their green bond use of proceeds and the projects to which funds have been allocated in the final report.

As of November 2021, the euro area green bond market in alignment with ICMA principles amounted to a total notional outstanding value of around EUR 530 billion. Bonds fulfilling all four ICMA principles and with third-party review made up 94% of that amount (see figure). In other words, the vast majority of green bonds is of the highest quality of greenness according to the standard.

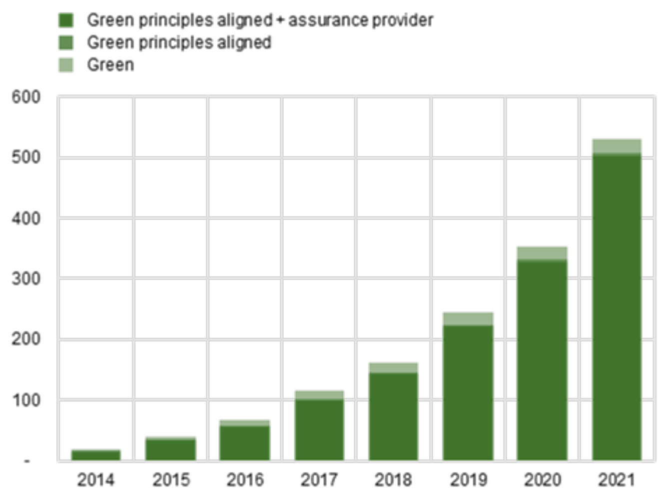

Figure 3: Total amount outstanding of euro area green bonds by classification

For this study, we use Bloomberg as a data provider since it identifies green bonds in align-

[3]These projects fall under the categories renewable energy, energy efficiency, pollution prevention and control, environmental sustainable of living natural resources and land use.

ment with the ICMA principles and indicates whether each of the four ICMA GBP is satisfied. In addition to that, there is a variable that provides information on whether a green bond is certified as green by a third-party assurance provider. These Bloomberg indicators allow for the classification of green bonds into three different levels of greenness: The lowest greenness is when bonds fulfil the use of proceeds principle, but not all other principles. Bonds that fulfil all four ICMA principles are considered of the second highest greenness. Finally, bonds of the highest greenness fulfil all ICMA principles and have also received the review of a third party. These bonds may be considered at lower risk of greenwashing.

3.2 Matching

The aim of this analysis is to understand whether green bonds are priced differently from conventional bonds by the market, purely based on their ”green” character. Issuers of green bonds and those of conventional bonds may differ, thus it is essential to eliminate issuer-based impacts on pricing from our analysis For example, firms that issue green bonds may be more aware of climate-related risks, may have lower emissions and could be overall better prepared for climate shocks (Flammer (2021)). As climate risks are not fully reflected in conventional risk metrics, such as probability of default or credit rating (Carbone et al. (2021)), issuer differences would lead to unobserved characteristics that are correlated with the issuance of green bonds which might have an unobserved impact on the pricing of green bonds. For this reason, it is essential to separate the impact of the green bond dummy from the impact of the green bond issuer. We achieve this by restricting our sample to only green and conventional bonds that have been issued by the same green bond issuers. In addition to that, a bond's price is also determined by its bond-level characteristics, such as the maturity, duration, seniority or coupon-type of a bond. We also account for this by minimising these differences in our sample selection as we apply a matching algorithm. The remainder of the section describes this matching procedure in greater detail.

As a first step to obtain our sample, we download from Bloomberg the entire universe of green bonds issued in the euro area as of end of July 2021. We use Bloomberg's green bond flag to identify green bonds satisfying ICMA's first principle on the *Use of Proceeds*. As of July 2021 the universe of all green bonds consisted of 1125 active and matured bonds. In a second step, we compiled a list of all the bond issuers from this universe of green bonds. This list of green bond issuers provided the basis for our universe of potential conventional bond matches as we used it to identify all conventional bonds listed in the ECB's internal Centralised Securities Database (CSDB). From this we obtained a list of more than 10,000,000 bonds that had been issued by the previously identified green bonds issuers. In the third step, we cleaned this universe of conventional bonds. As not all data providers use the same methodology to classify green bonds, this can lead to discrepancies in the universe of green bonds. To avoid that our sample of conventional bonds includes bonds classified as green by other data providers, we removed any bonds from the conventional bond universe that were not classified as green by Bloomberg, but showed a green indicator in Dealogic. We subsequently removed observations for which not all necessary bond characteristics were available and ended up with a subset of 25,655 green and conventional bonds.

On this subset, we applied a k-prototypes matching algorithm (Huang (1997), Huang (1998)) to match the most similar conventional bonds to our set of green bonds by minimising the following dissimilarity function:

$$d(GC) = \sum_{i=1}^{n} \omega_i (g_i - c_i)^2 + \sum_{j=n+1}^{m} \omega_j \delta(g_j c_j) \tag{1}$$

where Matrix G is a set of green bonds consisting of n normalised numerical variable vectors g_i and m categorical variable vectors g_j and C is a matrix of conventional bonds of n normalised numerical variable vectors c_i and m categorical variable vectors c_j. $\delta(g, c)$ is a dissimilarity function that takes the value 1 for each pair of categorical variables that are not alike and 0 if the pair of categorical variables is the same. The weights ω_i and ω_j can be chosen to represent the order of importance of each individual matching variable. For our sample, we match the nominal amount issued and duration with the weights 1 and 20, respectively, as numerical variables. Then we only allow for bond pairs for which the issuer and the calendar year of maturity was the same. Regarding categorical variables, we match bond seniority and currency with weights 100 each, debt type with weight 5 and issue date with 0.5.

This k-prototypes matching algorithm allows us to identify exactly one conventional bond for each green bond in our sample that was most similar according to the matching variables and was issued by the same issuer and had the same maturity year. After implementing all these steps, we obtained a sample of 124 euro area bond pairs, i.e. 248 individual bonds of 51 unique issuers.

3.3 Market data and descriptive statistics

The term *greenium* describes the idea that investors are willing to pay a premium to hold a green bond rather than a conventional bond, as they are willing to accept lower monetary returns in exchange for supporting environment-benefitting activities. If this is the case, it should essentially be reflected in better funding conditions for green bond issuers, thus lower yields for green bonds. However, as bonds frequently embed options that impact the bond value, yields might not always accurately reflect a bond's monetary value or be comparable. For this reason, we focus on the option-adjusted spread (OAS) in our analysis. Rather than simply looking at the discounted cash flows of a bond between its issuance and maturity, the OAS adjusts the bond z-spread for its embedded options.

For our analysis, we use daily data on the OAS from Bloomberg for our sample of 248 green and conventional bonds between 1 January 2016 and 31 October 2021. In addition to that, we use bid and ask prices, and the probability of default, as well as the following macro variables: 3-month euro area benchmark spread, the 10-year German government bond yield and the VIX index. For our final sample, we only keep observations for which all variables are populated for both bonds in a pair.

Table 1 shows the summary statistics of the green and conventional bonds in our sample, as well as t-tests on the differences between the groups. For static variables, we test the differences on the cross sectional sample and for dynamic variables, such as the OAS, the bid-ask spread and duration, on the panel data set. As can be seen from the first six rows, variables that have higher weights attributed by the matching algorithm, such as the average remaining maturity (in days) and seniority (1 for senior and 0 for subordinated), show no statistical difference between the groups. However, for variables such as average issue date (in days), coupon rate, amount issued and duration, the matching was imperfect. Moreover, we find that the bid-ask spread for green and conventional bonds is significantly different. Given the small sample size, we do not restrict our matching further, but instead run robustness test which can be found in table 7 to confirm the robustness of our results. Table 1 also shows the results of a t-test on the straight difference in OAS between green and conventional bonds which is statistically significant with an average of 6.58 bps. While this provides first tentative evidence for the presence of the greenium, this hypothesis is tested through more rigorous analyses in the next section.

	Conventional (mean)	Green (mean)	Difference	Standard error	Observations
Remaining maturity	7.083	7.209	-0.126	1.184	248
Issue date	20985.282[a]	21592.508	-607.226***	111.046	248
Seniority	0.839	0.871	-0.032	0.045	248
log(Amount issued)	18.436	19.007	-0.571	0.229	248
Coupon rate	1.570	1.046	0.524**	0.235	248
Duration	6.229	6.373	-0.144	0.657	248
ECB eligible	0.413	0.488	-0.075	0.063	248
OAS	59.214	52.634	6.580***	0.217	131922
Bid-ask spread	-0.419	-0.404	-0.015***	0.002	131922
Duration	6.082	6.249	-0.166***	0.029	131922

Table 1: Summary Statistics of green and conventional bonds

[a] Values are displayed as numeric (number of days since 1 Jan 1960). Green bonds' average issue date was 7 February 2019 while conventional bonds average issue date was 14 June 2017.

4 Results

4.1 Econometric specification

To investigate if there is a price differential between green and conventional bonds, we first introduce a preliminary step in our analysis by running a regression that explains bond yields by standard factors. In our analysis, we use option-adjusted spreads instead of bond yield as this allows us to better capture the value of a bond in excess of the current risk-free rate and its embedded options which should be considered in the bond return. We retain five categories established in the literature that explain the formation of the bond return: (i) a risk-free rate, duration and time to maturity; (ii) credit risk; (iii) risk aversion; (iv) liquidity premium; (v) intrinsic characteristics of bonds, such as maturity-type or pay-off seniority.

First, risk-free rates are key factors in bond pricing. We include risk-free interest rates of long and short maturity to account for the term structure of bonds: the 3-month EURIBOR and the German 10-year sovereign bond rate. We also include residual maturity and duration in the regression since bonds with longer maturity are expected to offer higher yields. Second, a key variable defining bond yields is credit risk. We use issuer's probability of default calculated by Bloomberg as a proxy for credit risk. Third, an important factor affecting bond yields is the market liquidity of bonds (Longstaff et al. (2005); Han and Zhou (2016); Bao et al. (2011)). We use the bid-ask spread as a measure of market illiquidity. Fourth, even if probabilities of default and recovery rates are constant, the risk premium may still vary due to a change in risk aversion. For example, during financial stress all bond spreads tend to rise independently of bond rating.

The increase in the implied volatility in the global stock markets, represented by the Vstoxx or the VIX, is used as a measure of financial stress and risk aversion (see, for example, Coudert et al. (2011), Rey (2016)).

Finally, we add a dummy variable to indicate whether a bond is eligible as ECB collateral as the effect of the ECB purchases on bond spreads and prices have been shown in a number of studies (Coudert and Salakhova (2020); Abidi and Miquel-Flores (2018); De Santis et al. (2018)). We also take into account the intrinsic features of bonds by adding coupon-type, issuer, currency, debt-type and seniority fixed effects. As we are interested in estimating the average difference in spreads between green and conventional bonds, we cannot use bond fixed-effects in this regression as these would absorb the difference in spread levels we are trying to measure. Instead, we use the above control variables to model any observable differences that would lead to a difference in spreads that cannot be attributed to the green bond dummy variables. This results in the following econometric specification:

$$OAS_{it} = \alpha_i + \beta Green_i + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{2}$$

In this panel set-up we observe each bond i at time t. We regress the outcome variable, i.e. the OAS_{it} on a set of dummy variables, α_i, i.e. issuer, year, debt-type, currency, coupon-type and seniority fixed-effects. X_{it} is a set of time-varying controls such as the bid-ask-spread, probability of default, log of the amount issued, bond eligibility as ECB collateral, duration and residual maturity. Mt are the macro variables 3M Euribor interest rate, the 10Y German Bund yield and the VIX Index. Finally, we add a green bond dummy variable equal to 1 if a bond is green and 0 if a bond is conventional. As observations of the same bond are likely correlated across time, we cluster standard errors at a bond level to account for serial correlation.

Under the assumption of unbiasedness, the estimator $\hat{\beta}$ can be interpreted as the effect of a bond being green on the bond spread, i.e. $\hat{\beta}$ can be interpreted as the greenium.

4.2 Greenium: baseline regression

As we would like to explore whether there are differences in pricing of green and conventional bonds, we start our analysis with the simplest question: Do green bonds exhibit a greenium, i.e. do they trade at systematically tighter spreads than conventional bonds? In other words, we test the following hypothesis:

Hypothesis 1: Green bonds trade at a greenium on the full sample over the period 2016-2021.

To do so, we first explain a bond's OAS with conventional metrics without the green dummy in the baseline regression specified in equation 2. In a next step, we add the green bond dummy to the regression to see whether being green has any additional explanatory value. The results of these regressions can be found in table 2.

	(1) Option-Adjusted Spread	(2) Option-Adjusted Spread
Green		-4.256*
		(2.270)
3M Euribor yield	102.545***	102.153***
	(9.902)	(9.875)
10Y Bund yield	7.771***	7.848***
	(2.043)	(2.057)
VIX Index	0.745***	0.744***
	(0.064)	(0.064)
Default probability	85.593	84.641
	(124.346)	(124.520)
Bid-ask spread	-20.769***	-20.846***
	(6.810)	(6.895)
ECB eligible	-15.633***	-14.926***
	(3.563)	(3.668)
Log(amount issued)	-3.083**	-2.455*
	(1.315)	(1.351)
Duration	-1.726	-1.924
	(1.300)	(1.344)
Couponrate	5.438***	4.349***
	(1.457)	(1.625)
Residual maturity	2.159*	2.331*
	(1.173)	(1.222)
Constant	133.323***	124.492***
	(27.081)	(27.371)
Issuer FE	Yes	Yes
Year FE	Yes	Yes
Currency FE	Yes	Yes
Seniority FE	Yes	Yes
Debt type FE	Yes	Yes
Coupon type FE	Yes	Yes
Observations	131922	131922
Number of bonds	248	248
R^2	0.697	0.699
Adjusted R^2	0.697	0.698

Standard errors in parentheses, clustered at the bond level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Greenium estimate across all bonds

Comparing the effects of the conventional risk metrics of the two regressions, we see that all standard factors explaining bond yields are significant and have the expected signs. The short-term and long-term interest rates have a positive and statistically significant effect on the OAS. Higher uncertainty in markets, indicated by a higher value of the VIX Index, shows a statistically significant correlation with higher bond spreads. The probability of default is positively correlated with the OAS, although not significant, which is likely due to issuer fixed-effects that absorb most of the differences in issuer-related risks between bonds. Moreover, lower market liquidity, modelled by higher values of the bid-ask spread is statistically significantly associated with 20.8 bps lower spreads, as there is more buying pressure in the market. Next, if a bond is eligible for use as ECB collateral which can be considered another risk metric for lower risk, it exhibits statistically significantly lower spreads by about 15- 15.6 bps. Higher coupon rates and longer residual maturity are associated with higher spreads.

Including the green bond dummy in the regression shows that all green bonds in our sample between 2016 and 2021, on average, exhibit lower spreads of about 4.3 bps but with low statistical significance at 10%. As we performed the matching of our sample, any bias of the greenium estimate, $\hat{\beta}$ should be minimal under the unconfoundedness assumption that matching on observable characteristics also captures potential differences in unobservable characteristics. This means that if the matching was perfect, we could expect that, on average, green and non-green bonds exhibit the same characteristics and thus the green bond dummy would be uncorrelated with the control variables. Indeed, comparing the results from both regressions, we find that the coefficients on conventional risk metrics are very similar regardless of whether the green bond dummy is included or not. This supports the argument that the $\hat{\beta}$ coefficient of the green dummy variable can be interpreted as the causal effect of bond's greenness on its pricing. Moreover, it provides more confidence in the matching as it shows that the correlation between the green bond dummy and the control variables is minimal. But to account for imperfections in the matching and to err on the side of caution, we include the set of control variables in all of the following specifications.

4.3 The Greenium and credibility of green bonds

As we saw in the previous section, we find a greenium of about 4.2 bps in the baseline regression on our entire sample. In a next step, we are interested in whether this greenium is different for different bonds within the sample. As can be seen from chart 2, there is large heterogeneity in the greenium within the bond pairs in our sample. This raises the question of whether there are any differences in the size of the greenium for different types of bonds or issuers. In particular, we are interested in whether the credibility of a green bond can be linked to a larger greenium. Greenwashing risks remain high as market participants are concerned about the legitimacy of environmental claims made by issuers. However, the risk of greenwashing might be mitigated through the use of third party certifications, such as e.g. the external review of satisfactory fulfilment of the ICMA green bond standards. Another aspect might be that issuers themselves are perceived as more credible, as their business model includes sustainable initiatives or as they might be part of a larger external organisation program that provides credibility to their efforts. Therefore, this section investigates the question of whether green bonds that are externally reviewed or are issued by more credible issuers exhibit a larger greenium than those which are not.

To assess the effect of green credibility, we start at the bond-level. In particular, we are interested in whether bonds that fulfil all four ICMA GBP and have also been externally reviewed exhibit a larger greenium. Thus, we split our sample of green bonds into two categories: those green bonds which fulfil all four ICMA and have also been externally reviewed and those green bonds which have not been externally reviewed or fulfil only some of the ICMA GBP. As seen in figure 3 , most green bonds are externally reviewed, so this divides our sample of 124 unique green bonds into 9 non-reviewed green bonds and 115 that have been externally reviewed. The classification allows us to test the following hypothesis by enriching our econometric baseline regression with an external review dummy variable:

Hypothesis 2: Only green bonds with external review trade at a greenium.

$$OAS_{it} = \alpha_i + \beta Green_i + \zeta ER_i + \gamma X_{it} + \delta M_t + \epsilon_{it} \tag{3}$$

The external review variable ER_i as specified in regression 3 is a dummy variable equal to 1 if the bond i is green, fulfils all four ICMA GBP and has been externally reviewed by a third party. It is 0 for all other bonds. As the variable can only be equal to 1 for bonds that are already green, it is also equal to the interaction term of the green bond dummy variable $Green_i$ and the external review variable ER_i. Thus, the coefficient ζ measures the difference in pricing between non-reviewed green bonds and green bonds that have been externally reviewed while β measures the difference in pricing between non-reviewed green and conventional bonds. The results of this regression can be found in table 3.

Indeed, we find that only externally reviewed green bonds trade at a statistically significant greenium of about 5.3 bps lower than conventional bonds and at 15.6 bps lower spreads than simple green bonds. The results even indicate that non-reviewed green bonds trade at higher

	(1) Option-Adjusted Spread
Green	10.287**
	(4.492)
External review	-15.635***
	(4.535)
Controls	Yes
Issuer FE	Yes
Year FE	Yes
Currency FE	Yes
Seniority FE	Yes
Debt type FE	Yes
Coupon type FE	Yes
Observations	131922
Number of bonds	248
R^2	0.701
Adjusted R^2	0.701

Standard errors in parentheses, clustered at the bond level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Greenium of externally reviewed bonds

spreads than conventional bonds which could point towards the market punishing less credible green bonds. Overall, the results reject the hypothesis that there is no difference in the pricing of green bonds with different levels of credibility and suggest that only externally reviewed bonds enjoy a greenium on their pricing.

In a next step, we are interested in whether there is also a difference in the greenium of green bonds for different issuers. Apart from the credibility of the bond itself, the characteristics of the issuer may affect the bond pricing. Investors may consider green bond issuers that already engage in environmentally sustainable projects more credible than issuers who do not. This motivates *Hypothesis 3: Only green bonds issued by green firms trade at a greenium.*

To test this hypothesis, we proceed by dividing our sample into different issuer sectors. We identify three broader clusters of sector types that issue green bonds in our sample: Alternative energy, banks and others. We identify alternative energy firms as energy firms that are not reliant on fossil fuels, but use the issuance of green bonds for investment in renewables and carry the NACE classification "Energy, gas, steam and air conditioning". Banks in our sample are classified by the NACE "Other monetary intermediation". Given the mix of the remaining issuer sectors, we classify them as "others". To test whether there are any differences between sectors, we run the same simple baseline regression in equation 2 with only the green bond dummy, but this time on each of the three sector subsets. The results can be found in table 4.

First, we find that bonds issued by firms in the alternative energy sector trade at a much

	(1) Alternative energy Option-Adjusted Spread	(2) Banks Option-Adjusted Spread	(3) Others Option-Adjusted Spread
Green	-22.170**	-10.044***	0.485
	(10.073)	(2.399)	(3.532)
Controls	Yes	Yes	Yes
Issuer FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Currency FE	Yes	Yes	Yes
Seniority FE	Yes	Yes	Yes
Debt type FE	Yes	Yes	Yes
Coupon type FE	Yes	Yes	Yes
Observations	12942	70034	32842
Number of bonds	22	160	46
R^2	0.727	0.754	0.680
Adjusted R^2	0.726	0.754	0.680

Standard errors in parentheses, clustered at the bond level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Greenium estimates for different sectors

larger and more significant greenium than the overall sample. On average, green bonds in this sector trade at 22.2 bps lower spreads than their conventional counterparts of the same issuer. This highlights the importance of issuer-credibility for the presence of the greenium and the economic size further suggests the commitment of investors to pay a premium for credible green bonds. Second, we find a highly significant and large greenium of about 10bps for green bonds issued by banks. Finally, for the subset of bonds that do not fall into these two categories, we no longer find a greenium. Overall, the results suggest that issuer credibility matters for the greenium and that only green bonds of credible issuers trade at tighter spreads than conventional bonds.

While it is evident that alternative energy issuers would provide more credibility to their green bonds, this is not necessarily the case for bank bonds. But upon taking a closer look at our sample of bank bonds, we find that roughly 70% of these banks are part of the United Nations Environmental Programme Finance Initiative (UNEP FI). The UNEP FI initiative was founded in 1992 and aims to mobilise private sector financing for sustainable development.[4] It is based on three principles; responsible banking, sustainable insurance and responsible investment. As this likely provides more credibility to banks that are part of UNEP FI than those who are not, we test if this is reflected in the greenium as well. Therefore, we test the following hypothesis:

Hypothesis 4: Only green bonds issued by banks engaged in UNEP FI trade at a greenium.

[4] See https://www.unepfi.org/ for further details

For this purpose we revisit our sub-sample of bank bonds, but this time we divide the sample further into two categories. We define a UNEP FI dummy variable that is equal to 1 for bonds that are issued by UNEP FI banks and 0 otherwise. We then add this dummy variable to our baseline regression 2, and also interact it with the green dummy. This results in the following difference-in-difference specification which measures the greenium of UNEP FI green bonds.

$$OAS_{it} = \alpha_i + \beta Green_i + \eta UNEPFI_{it} + \theta UNEPFI_{it} \times Green + \gamma X_{it} + \delta M_t + \epsilon_{it} \quad (4)$$

The coefficient of interest in this regression is the estimator $\hat{\theta}$ which measures the difference in the greenium between green bonds that are issued by UNEP FI banks and those which are not. In other words, $\hat{\theta}$ compares the sample of UNEP FI bond pairs and non-UNEP FI bond-pairs to test whether there is a difference in the difference of the green and conventional bonds OAS for the two samples.

	(1)
	Option-Adjusted Spread
Green	-4.880
	(3.214)
UNEP FI	-5.333
	(5.128)
Green × UNEP FI	-7.168*
	(4.150)
Controls	Yes
Issuer FE	Yes
Currency FE	Yes
Seniority FE	Yes
Debt type FE	Yes
Coupon type FE	Yes
Observations	70034
Number of Bonds	160
R^2	0.756
Adjusted R^2	0.756

Standard errors in parentheses, clustered at the bond level.
$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Table 5: Greenium for UNEP FI bank bonds

Table 5 summarises the results of this regression. We observe that adding the UNEP FI variable changes the result of our greenium estimates. In fact, we find that the coefficient on simple green bond dummy captured by $\hat{\beta}$, i.e. the difference in spreads between non-UNEPFI green and conventional bonds is much smaller and no longer significant. UNEP FI bonds overall seem to trade at 5.33 bps lower spreads, on average, although this result is not significant.

Finally, the parameter that we are most interested in, $\hat{\theta}$, shows a significant difference of about 7.2 bps [5] between the greenium for non-UNEPFI green bonds and UNEP FI green bonds. Therefore, we conclude that only green bonds that are issued by UNEP FI Banks and are thus perceived as more credible exhibit a greenium.

To summarise, our tests showed that green credibility is a primary determinant of green bond pricing. In particular, we found the following results: First, only green bonds that are externally reviewed and thus may signal greater ability to fulfil all four ICMA principles, exhibit a greenium. Second, bonds in the alternative energy sector exhibit a much larger greenium, owing to the sector's higher issuer credibility. Third, only bank bonds that are issued by UNEP FI banks trade at a greenium as engaging in a certified third-party sustainability initiative provides additional credibility to the issuing banks.

4.4 Greenium and investor demand

As we have seen in figure 2, there is not only large heterogeneity in the greenium within the sample for each point in time, but also over time. In fact, we can see that the median difference in OAS between green and conventional bonds, i.e. the median greenium only turns negative in the second quarter of 2020. This observation suggests that the greenium has changed over time and has only become prevalent in the most recent years. Therefore, this section documents the test of the following hypothesis:

Hypothesis 5: The greenium becomes more economically and statistically significant over time.

To confirm if the time-trend that is observable in the descriptive statistics of figure 2 holds also when testing it more formally, we revisit our baseline regression 2. However, this time, instead of using the entire sample for all time-periods, we divide our sample into monthly sub-samples. We then rerun the baseline regression on each of the sub-samples, to measure the greenium for each month of our time-series [6]. We then plot the $\hat{\beta}$ estimates for each month, as well as their corresponding 95 percent confidence intervals. The result of these regressions can be seen in figure 4.

What is visible in figure 4 is that the greenium does not only increase over time, but shows

[5] This estimate becomes more economically and statistically significant over time, as from 2020 onward, $\hat{\theta}$ is estimated at about 11.9 bps and 1% significance.

[6] The sample size before 09/2018 was not sufficiently large to perform this test.

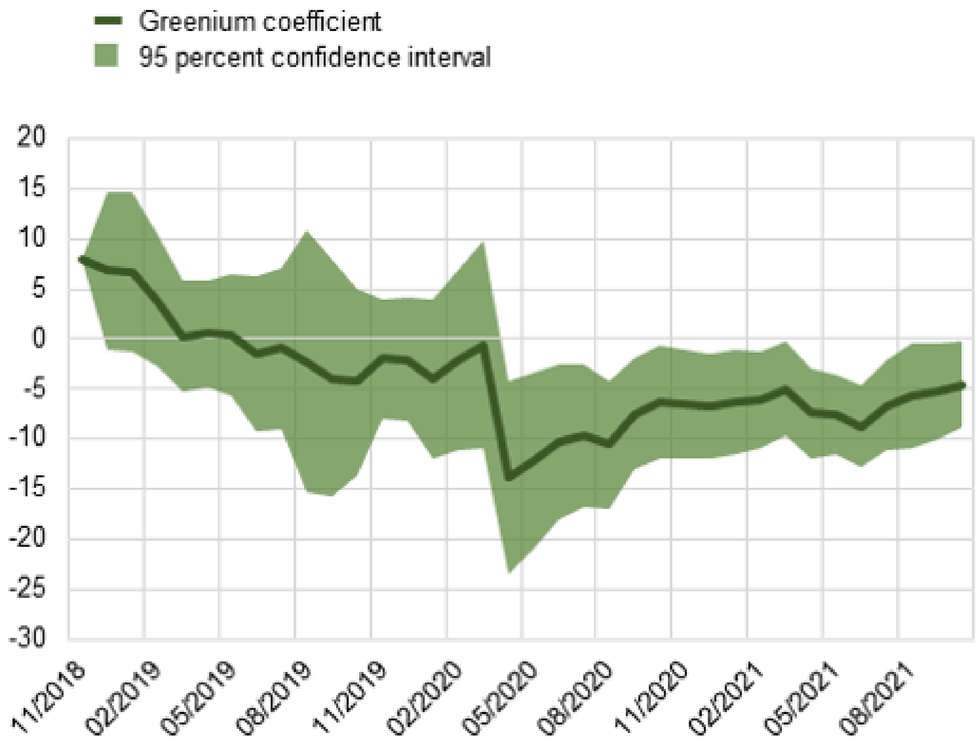

Figure 4: Greenium estimates over time

a distinct drop in its level from the second quarter of 2020. Before this period, it is neither negative, nor significant. This suggest that there must be one distinct force driving this result as it is not a gradual development, but rather displays a shift in the data.

To better understand where this time-development comes from, we perform the same regression on monthly subsets of the sectors we defined before. The plots of these monthly coefficients are seen in figure 5.

Figure 5 left shows a large greenium for the alternative energy sectors that we also found in the whole sample in table 4. Moreover, the greenium is very large and very stable, as it was consistently present since the second quarter of 2019. The bonds that are issued by neither the alternative energy sector nor banks show no greenium at all over the entire time-frame, and this observation is also rather stable. Finally, however, bank bonds show the same sudden drop in the greenium that we observe on the overall sample: Only from the second quarter of 2020, the greenium turns consistently negative and also highly significant. To summarise, we find that the greenium develops over time and is only present in the whole sample from the second quarter of 2020 onward. In contrast, for green bonds issued by the alternative energy sector, it has been present at a large economic magnitude over the entire time horizon. Green bank bonds are

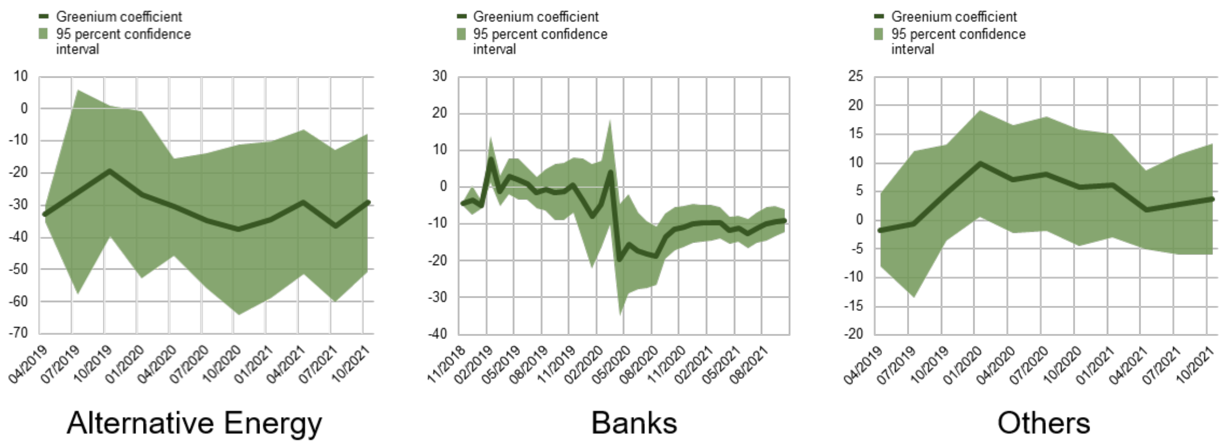

Figure 5: Greenium estimates over time by issuer sector

driving the time-development as they show the same notch in the data which divides the time series into two distinct parts.

Next, we would like to learn more about the forces that drive this observed development. As climate concerns rise, green bonds may attract more attention and also demand from investors who may want to contribute to climate-benefiting projects. Despite exponential growth of the green bond market seen previously in Figure 3, it still represents only about 3% of the total bond market. If the demand is very high and exceeds the supply, it may put pressure on the market and drive prices up. In the next hypothesis, we investigate if the demand for green bonds has changed over time and if it could explain the dynamics of the greenium.

Hypothesis 6: The greenium is driven in part by investors' demand.

For this, we complement our dataset on daily bond spreads with data from the Securities Holdings Statistics by Sector (SHSS) database. This database keeps track of the quarterly bond holdings of all euro area countries and further provides more granular information on the holdings of each sector. Using the unique ISIN of each bond as identifier, we are able to match quarterly holdings to the daily data on our bonds. This allows us to complement our data with information on how much the different sectors hold of each of the bonds in our matched sample for every quarter.

When it comes to measuring demand pressure, the difficult part is that the total demand observed such as, e.g. the total amount purchased is highly endogenous to the amount issued. As investors will simply absorb the supply that was issued, total holdings are not an ideal statistic to look at when we try to estimate demand pressure. Rather than focusing on total holdings, we thus are interested in whether we might see a change in relative holdings. In particular, we are interested in whether we can observe that some particular investors increased their relative share of their green bond holdings over time. If an investor has a strong preference for green bonds and is willing to pay a premium for them, she will increase the price of the bond more, the higher her share in the respective bond. Therefore, we compute the share of ownership of each sector for each bond by dividing the holdings of sector s of bond i by the total amount outstanding of bond i for each quarter.

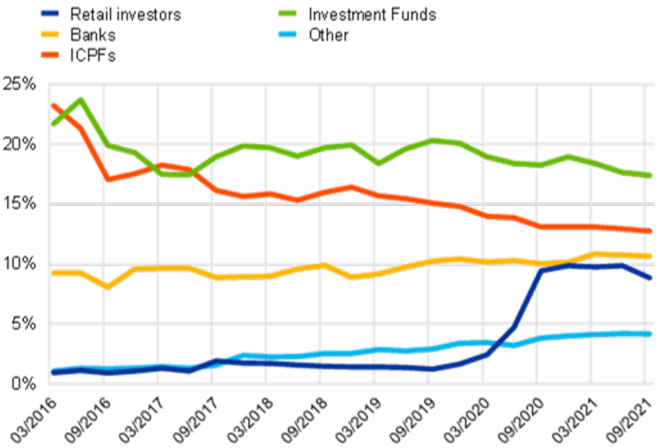

Figure 6: Average share of holdings by sector as a percentage of green bond amount outstanding

The plot of this time series is displayed in figure 6. It shows the average share each euro area holder sector holds of each bond. Not surprisingly, investment funds, insurance companies and pension funds (ICPFs), and banks hold the largest share of each bond. However, more interesting is the time-trend we observe in this chart. For retail investors (households and non-financial corporate holders) we observe a strong increase in the share of their holdings in the second quarter of 2020. This coincides exactly with the time for which we see the greenium drop dramatically in our sample. This suggests that retail investors may in particular drive the greenium trend. To further investigate this finding, we compare this pattern to the dynamics of the share of conventional bonds held by the different investor types. We do not find the same pattern which confirms that the development in the green bond market is distinct from the overall debt market. In a next step, we look more granularly at whether there is a difference in the type of green bonds for which the retail share has increased. What we find is quite striking and can be seen in figure 7: retail investors heavily increased their share of holdings in bank green bonds. For all other issuers, we do not find the same trend as indicated by the yellow line [7]. This might raise the question of why retail investors would buy specifically green bonds issued by banks. However, Euro Area Statistics data shows that bank bonds in general account for the largest share of retail investors' bond portfolio. This can be seen in Figure 8 which shows the total bond holdings of retail investors in Q3 2021 split by issuer sector. Therefore, it is not surprising that if retail investors would like to increase their exposure of green bonds, they would buy green bank bonds. Overall, these descriptive statistics suggest that retail investors' demand might drive the development of the greenium.

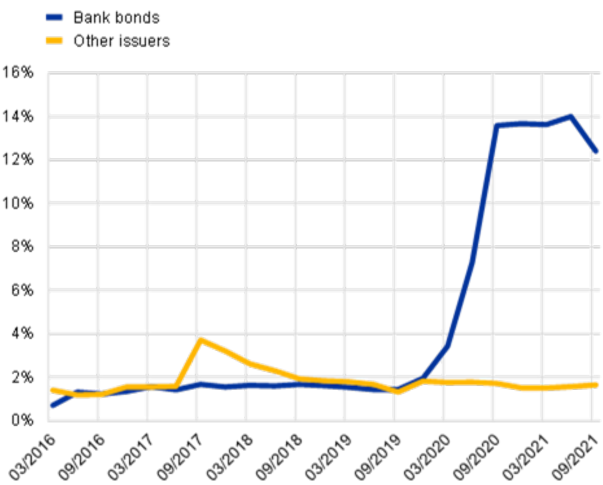

Figure 7: Retail investors' share of green bonds by issuer sector

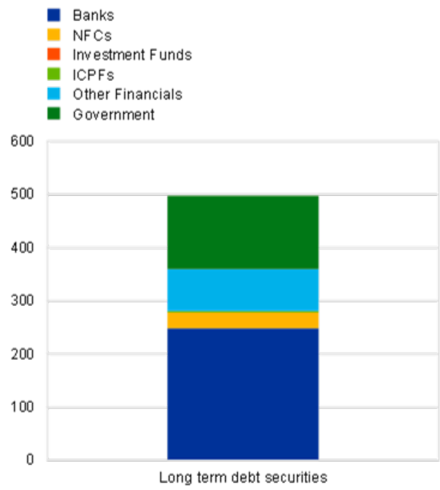

Figure 8: Retail investors' total holdings of bonds by issuer sector (Q3 2021)

To confirm these findings statistically, we define a "retail share" variable as the holdings of retail investors of bond i at time t divided by the total amount outstanding of bond i at time t. Moreover, we add another control variable "EA share" which is the share of other euro area investors of bond i at time t as the sum of all other sectors' holdings of bond i at time t divided by the the total amount outstanding of bond i at time t. We add these two variables to the baseline regression and also the interaction of the retail share with the green bond dummy variable. Given the structure of the holdings data, we also cluster standard errors by quarter. This gives us the following regression:

[7] We also do not see the same trend for non-green bank bonds. Instead, retail investors increased their share in conventional bank bonds gradually starting from 2018, with no visible jump in Q2 2020.

$$OAS_{it} = \alpha_i + \beta Green_i + \iota retailshare_{it} + \lambda \mathbf{retailshare_{it}} \times \mathbf{Green_i} + \kappa EAshare_{it} + \gamma X_{it} + \delta M_t + \epsilon_{it} \quad (5)$$

In this regression, the estimator $\hat{\lambda}$ can be interpreted as the difference in spreads that a green bond exhibits when retail investors change their share of this green bond from 0 to 100 percent. In other words and under the exogeneity assumption, it measures the premium that retail investors are willing to pay for a green bond relative to other investors. The results of this regression are summarised in table 6.

	(1) Option-Adjusted Spread
Green	-2.685
	(2.388)
Retail share	13.482
	(13.885)
Green × Retail share	-34.652**
	(13.854)
Euro area share other holders	0.000
	(0.000)
Controls	Yes
Issuer FE	Yes
Year FE	Yes
Currency FE	Yes
Seniority FE	Yes
Debt type FE	Yes
Coupon type FE	Yes
Observations	131922
Number of bonds	248
R^2	0.701
Adjusted R^2	0.700

Standard errors in parentheses, clustered at the bond and quarter level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Greenium for bonds held by retail investors

Indeed, we are able to confirm the correlations we have seen in the descriptive statistics. If retail investors increase their holdings in a green bond from 0 to 100 percent, the green bond trades, on average, at about 34.652 bps lower than a green bond that is held by other investors. Moreover, the baseline greenium is no longer significant. However, this result should be interpreted with caution, as it indicates the greenium that green bonds exhibit which are not held by retail investors at all but only by other investors. As for the majority of green bonds in our sample, the share of retail investors is not zero, these bonds should still, on average, exhibit a greenium. Nonetheless, the effect of retail holdings is highly significant and strongly suggest that it is correct to assume that retail investors' demand is driving the trend in the greenium. Furthermore, the coefficient $\hat{\kappa}$ which measures the difference in spreads that retail investors are paying for conventional bonds, shows that, if anything, retail investors buy conventional bonds that are more profitable. This difference between the price they pay for green bonds and the price they pay for conventional bonds further supports the argument that retail investors have strong preferences for green bonds and are willing to forgo profits just to hold a green bond.

To summarise, we find that the greenium develops over time and shows a sharp drop in the second quarter of 2020. Before this period, the greenium on the whole sample is not statistically significantly different from zero. Second, while the greenium for the alternative energy sector is very large and statistically significant over the whole time frame, green bank bonds seem to drive the development over time. They show the same strong decline in spreads in the second quarter of 2020 and stay at this low level thereafter. Finally, this trend in the greenium is driven by retail investors' demand who are willing to forgo profits of large economic magnitude to hold green bonds instead of conventional ones.

5 Discussion and policy implications

Our findings show changing dynamics in the greenium which are driven by investors' demand. This observation is similar to trends observed in other markets. First, Fig. 9 shows a very similar pattern in the spread between the returns of the MSCI Europe index and the MSCI Europe ESG leaders index. Pastor et al. (2021) find a similar trend in US equity markets with significant over-performance of green equity assets. van der Beck (2021) confirms this finding and shows that over-performance in US ESG equities is driven by inflows into ESG funds. We also observe a significant increase in holdings of ESG funds by euro area investors, particularly by retail investors and other investment funds.

The question is: what drives this increased interest in ESG/green assets? Pastor et al. (2021) argue that the excess return of green assets is driven by climate concerns. We investigate this explanation using the index of climate concern constructed by Bua et al. (2021) following the approach of Engle et al. (2020). However, we see that the index (Fig. 10) is rather volatile and exhibits no increasing trend. To obtain a trend Pastor et al. (2021) use a trick by computing a moving cumulative index of climate concern over the preceding three years with a decaying memory. Alternative explanations to the growing interest in green assets might be found in the increased engagement by policymakers and central banks in the discussion of the green transition, particularly in Europe, and the need for scaling up green finance and a larger publicity of ESG investing. This wider discussion may attract a large range of investors and may shift the investor base from primarily responsible investors to a wider public. Responsible investors may have the mandate and capacity to engage with issuers of green assets and to ascertain environmental benefits of green assets, i.e. green bonds. Mass investors, institutional or retail, may neither have the mandate nor the knowledge to do so. Thus, a regulatory standard, like the European Union Green Bond Standard (EUGBS) is crucial in bridging this knowledge gap as it would provide a clear definition of green bonds and establish requirements to assure that proceeds raised from green bonds contribute to the transition to a more sustainable and low-carbon economy.

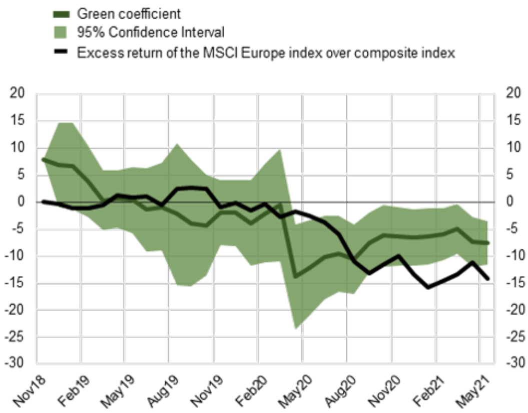

Figure 9: Evolution of the greenium and excess return of composite index over ESG equities

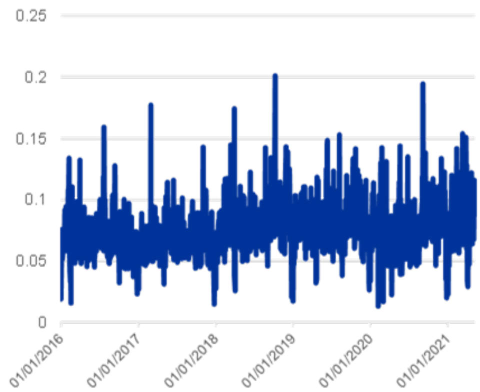

Figure 10: Index of Climate concern from Bua et al. (2021)

So far, there is mixed evidence if the issuance of green bonds is associated with a reduction in issuers' carbon emissions. Flammer (2021), Fatica and Panzica (2021) show that only certified green bonds are associated with emission reductions at issuer level, while Ehler et al. (2020) find no relationship. One reason why green bonds may fail to deliver an emissions reduction and other environmental benefits is because green bonds, by definition, raise funding for specific projects and neglect issuers' overall commitment and strategy regarding climate change. This may also explain the highly economic and statistical significance of the greenium for green bonds issued by firms in alternative energy sectors. These firms can be easily identified as green by investors. Ehler et al. (2020) also raise this point and suggest a rating system to rank firms according to their levels of emissions. An issue with this solution is that firms with currently high levels of emissions may have difficulties to attract funding which is needed for the transition. However, if the green rating takes into account information on firms' commitment to the transition and assesses the credibility of forward-looking targets and transition plans, it may be a very efficient instrument. Carbone et al. (2021) show that markets do appreciate firms' disclosures of current emissions as well as setting forward-looking targets to cut emissions as such firms exhibit lower carbon risk. Furthermore, the effect of climate commitments on market credit risk tends to be stronger for more ambitious targets.

6 Robustness

We perform a series of robustness tests to address potential concerns and reject other explanations. First, we run robustness checks to account for imperfect matching in our sample, by repeating regression 2 on restricted samples across different dimensions. Table 7 shows the results of this exercise. In the first column, we exclude any callable or convertible bonds in our regression to account for the effect of implied options that might bias our estimates on the OAS. We find a significant greenium of -4.4 bps in this sample. Next, we only look at a sample of 111 bond pairs that had a lower difference in average duration than the average pair and the difference in OAS was estimated at 10.7 bps with statistical significance.[8] Column 3 shows the results of a regression on a sub-sample of bonds for which the pairs with the 10 percent highest difference in average bid-ask spread have been removed. For this sub-sample, the difference in bid-ask spread between green and conventional bonds is no longer significant and green and conventional bonds have an average bid-ask spread of 0.3845 and 0.3850 bps, respectively. We find that the greenium is larger than in the baseline and statistically significant at about -5.6 bps. Then we look at a sample of 88 bonds for which the amount issued was the same for the green and conventional bonds. Again, the greenium is large and statistically significant with -10.865 bps. Restricting the sample to pairs where both bonds were issued within 1 year from each other, gives an estimate of -3.9 bps for the whole sample. Although not statistically significant, this seems to be driven by the different sample composition which includes a higher weight of simple green bonds, as excluding bonds without external review results in a greenium estimate of -6.7 bps which is significant at the 5 % level. Finally, we look at bond pairs for which the

[8]For this sub-sample of bonds, the difference in average duration was still statistically significant, with an average of 5.45bps for green and 5.64 bps for non-green bonds. Nonetheless, we used this sub-sample to eliminate large outlier pairs as it was not possible to construct a sub-sample for which the difference was no longer significant.

difference in coupon rate is less than 20 bps. In this sub-sample, green bonds have an average coupon rate of 0.57 bps while non-green bonds have an average coupon rate of 0.59 bps, and the difference is no longer statistically significant. Again, our results are confirmed with a greenium estimate of -16.6 bps.

	(1) Straight Bonds	(2) Duration	(3) Bid-Ask	(4) Amount Issued	(5) Issue Date	(6) Couponrate
Green	-4.430**	-10.707***	-5.596**	-10.865***	-3.919	-16.558***
	(1.763)	(2.602)	(2.524)	(3.924)	(2.487)	(4.384)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Issuer FE	Yes	Yes	Yes	Yes	Yes	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes	Yes
Seniority FE	Yes	Yes	Yes	Yes	Yes	Yes
Debt type FE	Yes	Yes	Yes	Yes	Yes	Yes
Coupon type FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	106670	68784	117924	30404	49892	21640
Number of bonds	190	186	222	88	98	46
R^2	0.730	0.770	0.695	0.679	0.786	0.726
Adjusted R^2	0.730	0.770	0.695	0.678	0.786	0.726

Standard errors in parentheses, clustered at the bond level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Robstness checks on restricted sample

The next set of robustness checks tests different explanations for our results. First, we replace issuer fixed effects by issuer-time fixed effects and rerun the baseline regression of the greenium described in equation 2. This means that macro variables are omitted but the specification instead allows us to account for issuer-specific shocks over time that could potentially drive the greenium. As visible from table 8, column (1), the greenium estimate becomes slightly larger, -4.6 bps, and preserves its statistical significance.

Next, we test if clustering standard errors at a pair level would affect our results. Only the result in the baseline regression does not hold with significance as can be seen in column (2) of table 8. The baseline result on the greenium in the full sample for all periods switches from significant at 7.2% to insignificant with a p-value of 11.7%. All the other results remain largely intact. The non-significant result for the baseline regression seems to be driven by low greenness bonds as performing the same regression 2 on a sub-sample of only externally reviewed bonds, we still find a significant estimate of the greenium.

Furthermore, we test whether the greenium differs across different bond liquidities, by adding an interaction term of the green dummy with the bid- ask spread. We don't find any significant results on the interaction of bid-ask spread and the greenium, suggesting that the greenium is homogeneous across different levels of liquidity. In column (4), we repeat the regression of the

	(1) Issuer-Time Fixed-Effects	(2) Pair-clustered Standard Errors	(3) Bid-ask interaction	(4) Bank bonds without German Banks	(5) All results
Green	-4.603*	-4.256	-7.449**	-4.416*	16.447***
	(2.477)	(2.694)	(3.032)	(2.518)	(5.294)
External review					-16.611***
					(5.848)
Green× Bid-ask			0.423		
			(6.703)		
Green × Alt. Energy					-23.694***
					(8.235)
Green× UNEP FI					-4.122
					(3.509)
Green × Retail share					-26.862**
					(12.786)
Alt. Energy					0.000
					(0.000)
UNEP FI					7.656**
					(3.444)
Retail share					8.701
					(13.436)
Share other holders					0.000
					(0.000)
Controls	Yes	Yes	Yes	Yes	Yes
Issuer FE	Issuer-Time FE	Yes	Yes	Yes	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes
Seniority FE	Yes	Yes	Yes	Yes	Yes
Debt type FE	Yes	Yes	Yes	Yes	Yes
Coupon type FE	Yes	Yes	Yes	Yes	Yes
Observations	131977	131977	134500	47226	131977
Number of bonds	248	248	248	72	248
R^2	0.849	0.713	0.699	0.791	0.725
Adjusted R^2	0.796	0.713	0.699	0.791	0.725

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

Table 8: Robustness checks

greenium on bank bonds from table 4, but this time excluding German bank bonds. The reason for this is that German bank bonds account for almost half of our sample on bank bonds and are issued by only four different issuers. We find that dropping these observations does not change our results on bank bonds in this restricted sample. Across all periods, we find a statistically significant greenium of about -4.4 bps.

Finally, as shown in column (5) of table 6, we test all of the explanatory factors in the same regression. First of all, we are able to confirm the result of the external review effect. The difference in the greenium between simple green and externally reviewed bonds is statistically significant at -16.6 bps, similar to the -15.6 bps in the main regression. Again, simple green bonds trade at a positive spread compared to their conventional counterparts. Next, we add an interaction term of alternative energy bonds with the green dummy variable.[9] We find that alternative energy bonds trade at about -23.7 bps lower than other green bonds compared to -22.2 bps in the main regression. This allows us to confirm the second set of results. Next, we test whether UNEP FI bonds exhibit a statistically significantly higher greenium. Although we find that, on average, UNEP FI green bonds trade at lower spreads than conventional bonds, this result is no longer statistically significant. It seems, therefore, that other factors, such as the bond credibility or the demand pressure cannot be disentangled in this regression from the participation in UNEP FI [10]. Finally, we also confirm the robustness of the effect of retail investor purchases. While the effect size of -26.9 bps is slightly smaller than the estimate of -34.7 bps in the main regression, the economic magnitude the economic relevance is comparable and corroborates the relevance of retail investors' demand for the greenium.

Moreover, we test the time trend of the greenium using a different specification. Instead of running the regression on bond level observation, we look at the pair level. For this, we merge the daily observations of all green bonds with the daily observations of their conventional counterparts. We then compute the difference in any numeric variables and rerun the regression on monthly sub-samples. Instead of including a green bond dummy, we regress the daily difference in OAS for each pair on a constant and the difference in numerical control variables. In this case, the constant estimates the greenium. The results of this exercise are plotted in figure 11. We find the same time trend in this regression and the greenium becomes statistically significant in the second quarter of 2020, although only at 10 percent significance.

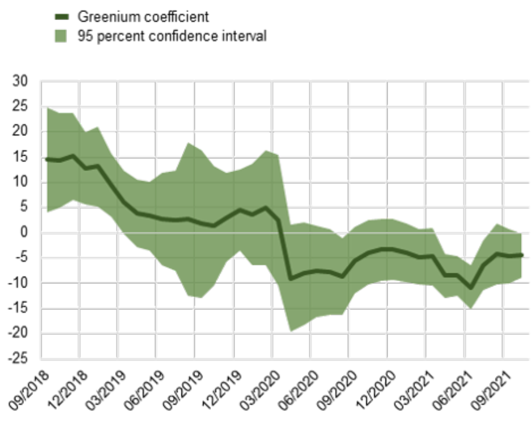

Figure 11: Greenium trend on pairwise regression

[9] The simple alternative energy dummy variable is omitted due to the issuer fixed effects.

[10] Running the same regression on observations from 2020 onward, however, shows a significant estimate of the interaction term of UNEP FI and the green dummy and all other variables as well.

	(1) Credible Sector	(2) External Review
Green	3.626	8.824*
	(2.536)	(4.533)
Green × Credible sector × Retail share	208.088**	
	(95.340)	
Green × Credible sector	-12.706***	
	(4.047)	
Credible sector × Retail share	-66.904***	
	(14.567)	
Green× Retail share	-216.235**	681.292
	(92.451)	(993.383)
External review × Retail share		-709.396
		(998.908)
External review		-12.764**
		(5.041)
Credible Sector	13.733***	
	(4.149)	
Retail share	67.402***	10.129
	(13.848)	(13.875)
Controls	Yes	Yes
Issuer FE	Yes	Yes
Year FE	Yes	Yes
Currency FE	Yes	Yes
Seniority FE	Yes	Yes
Debt type FE	Yes	Yes
Coupon type FE	Yes	Yes
Observations	131922	131922
Number of Bonds	248	248
R^2	0.706	0.703
Adjusted R^2	0.705	0.703

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

Table 9: Retail share interaction with issuer and bond credibility

Our findings also raise the question if there are any interactions between the individual results. In particular, we test whether the greenium is stronger if retail investors buy green bonds of credible issuers or with external review. Column 1 shows the results of the interaction between retail investor demand and credible sectors. The interaction between the green bond dummy, the credible sector dummy (as defined as a bond by issued by UNEP FI banks or alternative energy firms) and household demand has a positive coefficient, suggesting that the effects do not reinforce each other. However, while this means that we cannot find any additional evidence for retail investor preferences for green bonds from credible sectors, the absolute value of the greenium is still large for every dimension individually. Second, we also assessed the interaction between the external review dummy and retail investor demand. While the point estimates suggest that, on average, retail investors are only willing to pay a premium for externally reviewed bonds, this is not statistically significant, probably due to the limited sample size. The limited sample size also does not allow us to test whether there is an interaction in the greenium between credible issuers and credible bonds.

To summarise, we are able to confirm the robustness of the factors that influence the greenium such as the bond credibility, credibility by greener issuers, investor demand and the time trend of the greenium. Only the result of greener intermediaries was no longer robust as it seems that the regression was not able to sufficiently disentangle other factors. Furthermore, we are not able to confirm that there is any additional effect on retail investor demand if an issuer or a bond is more credible.

7 Conclusion

Green bonds have demonstrated significant growth since 2015 and thus attracted a lot of attention as a potential instrument to help finance the transition to a low-carbon economy. An important question is if companies issuing green bonds and contributing to the transition benefit from cheaper funding. Several studies argue that responsible investors may have non-pecuniary objectives and are thus ready to bear lower returns of green investments. In this paper we address this question by investigating if green bonds trade at a negative spread to conventional bonds, i.e. at a greenium, in the secondary markets. While cost of funding for companies is defined by bids in the primary markets, secondary markets nevertheless have a strong effect on primary markets via the price and liquidity of bonds (Bond et al. (2012)). Furthermore, we analyse how the greenium evolves over time and what factors can explain it. To answer these questions, we first match green and non-green bonds issued in the euro area to obtain pairs of comparable bonds. Within a pair, bonds are similar across several dimensions: the same issuer, maturity, duration, seniority and coupon-type. Then, on the matched sample, we perform an econometric analysis on a sample of green bonds from 2016 to 2021. We show that option-adjusted spreads (OAS) of bonds in our sample are explained by all standard factors such as risk-free interest rates, credit risk, liquidity, risk-aversion, and bonds intrinsic characteristics, e.g., maturity, duration, coupon. Nevertheless, a green factor provides additional information as introducing a dummy for green bonds results in a negative and significant coefficient, though with relatively low statistical and economic significance.

Our findings show that, first, in the absence of regulatory standards, investors seek credibility of green bonds and issuers. In terms of bond credibility, we find that only bonds with external review trade at both a statistically and economically significant greenium. Regarding issuers' credibility, we define firms in the alternative energy sector as credible as well as banks that signed for the United Nations Environmental Program for Financial Initiative (UNEP FI). We find that only green bonds issued by credible companies trade at a statistically and economically significant greenium. The presence of the greenium is still debated in the literature, and our findings contribute to this debate by providing additional evidence on the presence of the greenium in secondary markets, and, particularly, on the importance of credibility for green bonds. Our findings are similar to those of Fatica et al. (2021) and Kapraun et al. (2021) for primary markets, especially as only green bonds with external review trade at a greenium. Findings by Kapraun et al. (2021) show also a difference in the greenium across currencies and issuer countries, suggesting that issuers from countries/regions with higher credibility like the euro area enjoy better funding conditions on green bonds. Other papers, like Flammer (2021), on the other hand, find no greenium in primary markets. Though given the absence of a common worldwide standard that defines a green bond, there is important heterogeneity in green bonds across currencies, countries, and sectors, and thus, when comparing results across studies, one should keep in mind the data and sample on which the analysis was performed.

We also find that the greenium evolves over time and that it is (retail) investors' demand that explains these dynamics. To our knowledge, we are the first to demonstrate this result which, in its turn, corroborates findings in other types of green assets, like equity and ESG investment funds. van der Beck (2021) show that equity prices of green assets are driven by investors' flows into ESG funds, while Pastor et al. (2021) find that the recent increase in returns of green assets is purely driven by climate concerns and not by firms' fundamentals.

This paper also contributes to an important policy debate about the European Union Green Bond Standard (EU GBS). In particular, it exposes the need for a regulatory standard that will provide a clear definition of green bonds and requirements to assure that proceeds raised from the issuance of green bonds contribute to the transition. Institutional investors may not have strong incentives to monitor the environmental performance of green bonds while retail investors may not have the capacity and knowledge to so. Thus, a regulatory standard is key to channel investments into projects fostering the transition. Furthermore, only a common standard can help avoid investors' confusion, loss of confidence and potential runs even on the best green bonds.

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