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The effect of pro-environmental preferences on bond prices: Evidence from green bonds

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ABSTRACT

We use green bonds as an instrument to identify the effect of non-pecuniary motives, specifically pro-environmental preferences, on bond market prices. We perform a matching method, followed by a two-step regression procedure, to estimate the yield differential between a green bond and a counterfactual conventional bond from July 2013 to December 2017. The results suggest a small negative premium: the yield of a green bond is lower than that of a conventional bond. On average, the premium is -2 basis points for the entire sample and for euro and USD bonds separately. We show that this negative premium is more pronounced for financial and low-rated bonds. The results emphasize the low impact of investors' pro-environmental preferences on bond prices, which does not represent, at this stage, a disincentive for investors to support the expansion of the green bond market.

1. Introduction

In response to environmental crises, financial investors have recently taken up the challenge and become key actors in the energy and environmental transition. This pivotal role is notably due to their ability to mobilize a considerable amount of funds: the global stock of manageable assets,[2] which amounted to USD 160 trillion in 2016 (Financial Stability Board, 2018), can be compared to the infrastructure investment needs of 6.9 trillion over the next 15 years to be consistent with the 2 degrees Celsius threshold (OECD, 2017a). Several initiatives have been launched to redirect assets toward green investments. For example, by signing the Montreal Carbon Pledge,[3] more than 120 investors with assets under management worth more than USD 10 trillion have committed to supporting the development of the green bond market and to measuring and publishing the carbon footprint of their investments.

The drivers to invest in assets with a low environmental impact (*green assets* hereafter) can be related to financial motives, such as the expectation of better financial performance (Nilsson, 2008; Bauer and Smeets, 2015; Hartzmark and Sussman, 2018) or a lower risk (Krüger, 2015). These drivers can also be attributable to non-pecuniary motives. Preferences linked to pro-social and

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[2] This amount corresponds to the *Monitoring Universe of Non-bank Financial Intermediation*, including all non-bank financial intermediation: insurance corporations, pension funds, other financial intermediaries and financial auxiliaries.

[3] http://montrealpledge.org/.

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pro-environmental[4] norms and attitudes lead investors to increase their investments in the assets of companies behaving more ethically (Hong and Kacperczyk, 2009; Riedl and Smeets, 2017; Hartzmark and Sussman, 2018). The incentive is not necessarily a proprietary choice of the asset manager: it can be delegated by the asset owner through the *delegated philanthropy* mechanism described by Benabou and Tirole (2010).

The price impact of investors' preferences for green assets has been broadly documented in the literature. Although there is no unanimity on the subject, most of the works focusing on the bond market suggest that companies with high environmental performance benefit from a lower cost of capital (see Section 2 for an extensive literature review). Authors mainly attribute this negative yield differential to a financial reality: intangible asset creation (Porter and van der Linde, 1995; Hart, 1995; Jones, 1995; Ambec and Lanoie, 2008; Flammer, 2015) as well as better risk management and mitigation (Ambec and Lanoie, 2008; Bauer and Hann, 2014), both being imperfectly captured by rating agencies' models (Ge and Liu, 2015; Oikonomou et al., 2014). However, the existing literature does not identify whether, and by how much, this yield differential is driven by non-pecunary motives.

By integrating into the utility function of a group of investors an appetite for certain types of assets in addition to their expectations regarding return and risk, Fama and French (2007) show that investors' *tastes* modify equilibrium prices. Nevertheless, few studies have empirically isolated the impact of non-pecuniary motives on market prices. Focusing on sin stocks and controlling for a battery of financial indicators, Hong and Kacperczyk (2009) show that social norms lead to a 2.5% higher return for sin stocks than non-sin stocks. However, the analysis of non-pecuniary motives on the stock market implies comparing the financial securities of different companies and thus makes it very difficult to identify the effect.

In this paper, we exploit the bond market to clearly identify the impact of pro-environmental preferences on prices. To do so, we use green bonds as an instrument: we compare each green bond with an otherwise identical counterfactual conventional bond. Unlike two bonds issued by companies with different environmental performances, green and conventional bonds of the same company are subject to the same financial risk once all their differences have been controlled. Comparing the yield of a green bond and that of a conventional counterfactual thus makes it possible to isolate the impact of pro-environmental preferences on bond prices.

Therefore, this paper aims to provide answers to the following two questions:

Research question 1: Do pro-environmental preferences translate into bond market prices?

Research question 2: If so, do they apply uniformly across the entire bond market?

The study of the green bond market is made possible by the recent accelerated development of this asset class, which has been supported by the definition of the Green Bond Principles[5] providing issuers with guidance and investors with reliable information about environmental impacts. The labeled green bond market reached USD 301 billion outstanding in December 2017. Green bond issuances rose to USD 163 billion in 2017, up 68% from the previous year. Government-related bonds, including government, national and supranational agencies, account for 30% of the total, while 32% are financial bonds and 21% are bonds issued by energy companies. Among the 44% of the bonds rated by S&P, Moody's or Fitch in the entire database, 90% are investment-grade bonds, and 10% are high-yield bonds. The main currencies involved are the USD and the euro (EUR), each of which accounts for one-third of the total outstanding green bond debt.

We identify the effect of pro-environmental preferences through a *green bond premium*, which is defined as the yield differential between a green bond and an otherwise identical conventional bond. We perform an analysis on 110 green bonds on the secondary market between July 2013 and December 2017. This sample accounts for 10% of the number and 17% of the amount of green bonds issued worldwide at the end of 2017. We first use a matching method to estimate the yield of an equivalent synthetic conventional bond for each live green bond issued in the global universe on December 31, 2017. To do so, we build a counterfactual conventional bond from the same issuer, having the same maturity, currency, rating, bond structure, seniority, collateral and coupon type, as well as a limited difference in issue date and size. In the second stage, we control for the residual difference in liquidity between each green bond and its counterfactual to extract a green premium by performing a fixed-effects panel regression: the green premium is the unobserved specific effect of the regression of the yield differential on the bonds' liquidity differential. By performing a panel regression on matched pairs of bonds for which the characteristics are identical except for the green feature of one of the two, we circumvent two biases inherent in a cross-sectional regression of yields on bonds' characteristics: an omitted variables bias and a bias related to overweighting assets with the longest price history. Finally, to identify the factors affecting the costliness of a green bond, we explain these green premia according to the specific characteristics of the bonds through a cross-sectional regression.

We show that there exists a small, albeit significant, negative green bond premium of -2 basis points (bps) in our sample. The sector and the rating are significant drivers of the premium: the negative premium is greater[6] for financial bonds and low-rated bonds. Through several robustness tests, we verify that the premium is neither a risk premium nor a market premium, that the matching method is sufficiently stringent, and that the average and median premia remained negative on a monthly basis from May 2016 onward. We also show that the estimated premium in our sample has a reasonable chance of reflecting a similar phenomenon across the total sample of green bonds.

Our contribution to the literature is threefold. First, we contribute to the literature on non-pecuniary motives in ethical investing. We use green bonds as an instrument to cleanly identify the effect of pro-environmental preferences on the bond market. Although social and environmental preferences can have a substantial positive impact on investment inflows in ethical funds and assets, the 2-bps negative yield premium on green bonds shows that the impact of pro-environmental motives on bond prices is still limited. We also contribute to the literature linking the cost of debt and the company's environmental performance. The low negative green bond premium, which is related to the price impact of pro-environmental preferences, suggests that the lower cost of debt for companies with good environmental performances should be more related to a lower level of risk than to non-pecuniary motives. Third, this study on the valuation of green bonds complying with the Green Bonds Principles is the most extensive in terms of geographical scope, number of bonds studied as well as price history. The methodology developed–which, more generally, can be used to estimate the valuation of other types of bonds of which

[4] Pro-social and pro-environmental motives refer to investors' interest in social and environmental issues per se in their investment decisions.

[5] The 2017 voluntary process guidelines for issuing green bonds are summarized in https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/GreenBondsBrochure-JUNE2017.pdf.

[6] When the premium is negative, we use the terms *greater negative premium* and *lower premium* interchangeably to mean that the negative premium has a higher absolute value.

the proceeds are directed to a specific use, such as *social bonds*[7] – includes strict liquidity control and is supplemented by numerous robustness tests.

The negative yield premium of 2 bps has distinct implications for the various market players; it does not represent a notable disincentive for investors who should not substitute their purchase of green bonds with conventional bonds. Moreover, although low, this premium demonstrates investors' appetite for green bond issues and supports the hypothesis that this instrument offers issuers the opportunity to broaden their debtholder base. Finally, from the supervisory authority perspective, while this negative premium underlines a certain buying pressure on green bonds, it does not yet reveal any substantial valuation discrepancy between green and conventional bonds.

This paper is organized as follows. In the second section, the literature on the topic of interest is reviewed. The method used to build the data on which this study is based is described in the third section. Our empirical approach is described in the fourth section, and the results obtained using the empirical model are presented in section five. The robustness checks run are described in the sixth section, and the results are discussed in section seven. The conclusions of our findings are summarized in section eight.

2. Literature review

Numerous authors have addressed the effects of corporate social performance (CSP),[8] especially the effects related to good environmental performance,[9] on companies' stock returns (Konar and Cohen, 2001; Derwall et al., 2005; Kempf and Osthoff, 2007; Semenova and Hassel, 2008; Statman and Glushkov, 2009; Dixon, 2010). Although no consensus has been reached, most of the articles published have suggested that CSP has a positive impact on companies' financial performance. Moreover, CSP has been found to have similar effects on the cost of equity capital: firms with better CSP (ElGhoul et al., 2011; Dhaliwal et al., 2011)[10] or a low environmental impact (Heinkel et al., 2001; Sharfman and Fernando, 2008; Chava, 2014) benefit from a lower cost of equity capital. However, these findings are not necessarily transferable to the debt market for at least two reasons. First, the payoff profile of a debtholder differs from that of a stockholder (Oikonomou et al., 2014; Ge and Liu, 2015): Merton (1973) specifies that a bond payoff can be replicated by the purchase of a stock and the sale of a call option on the same asset. Since bondholders have little upside available, it is crucial for them to analyze and assess all the downside risks, including environmental hazards. This need for insurance against a market downturn is all the more relevant for socially responsible investing, as CSP leads to better credit ratings (Jiraporn et al., 2014) and has a strong effect on a company's default risk reduction (Sun and Cui, 2014). Second, as previously suggested by Oikonomou et al. (2014), firms are more sensitive to the pressure exerted by bond market investors because firms refinance via the debt market more frequently than they increase their capital. This pressure can be all the more easily exerted because debt instruments are frequently held by institutional investors with advanced risk analysis capacities.

Although several studies have focused on the effects of CSP on corporate bond yields, no unequivocal conclusions have yet been reached on this topic. Magnanelli and Izzo (2017), using a database of 332 companies worldwide with 1641 observations from 2005 to 2009, are among the few authors showing that CSP increases the cost of debt. In line with the shareholder theory, their results support the assertion that CSR is considered "a waste of resources that can negatively affect the performance of the firm." Conversely, Menz (2010) focuses on the European corporate bond market and observes that socially responsible firms suffer more from a greater credit spread than do non-socially responsible companies, although this finding is weakly significant. Likewise, Stellner et al. (2015) obtain relatively weak evidence that good CSP systematically reduces credit risks. Other authors, however, report a significant negative relationship between CSP and the cost of debt. Oikonomou et al. (2014) show that for U.S. corporate debt, good CSR performance is rewarded by lower bond yields and CSR irresponsibility is positively correlated with financial risk. Based on information provided by a cross-industrial sample of U.S. public corporations, Bauer and Hann (2014) establish that environmental strengths are associated with lower bond yields. Other authors, such as Klock et al. (2005), using U.S. data, and Ghouma et al. (2018), using Canadian data, report that bond spreads decline with the quality of corporate governance. Klock et al. (2005) notably show that compared to firms with the strongest shareholder rights (proxied by weak antitakeover provisions), firms with the strongest management rights (strongest antitakeover provisions) benefited from a 34 bps reduction in the cost of debt for the period 1990–2000. Ge and Liu (2015) focus on the effects of CSP disclosure on the spreads of new corporate bonds issued in the U.S. primary market and establish that firms reporting favorable CSPs enjoy lower bond spreads. Hasan et al. (2017) also examine the primary market of U.S. firms from 1990 to 2012 and find that firms headquartered in U.S. counties with higher levels of social capital benefit from lower at-issue bond spreads. Finally, although the financing of private loans and public bonds must be analyzed differently mainly because banks have access to more information than bondholders, Goss and Roberts (2011) reach similar conclusions after examining the impact of the CSR scores of 3996 U.S. companies on the cost of the companies' bank loans. They also establish that firms with the lowest CSR scores pay between 7 and 18 bps more than the most responsible firms.

However, few articles have been published on the specific cost of green bonds. Table 1 summarizes the results of and differences between these studies.

In contrast to the analyses in the papers presented above, the analysis of the green bond yield is not based on the CSP of the issuing company because the green bond label is associated with the funded projects and not with the issuer type. Thus, we can compare a green bond yield with the yield of a similar conventional bond from the same issuer.

HSBC (2016) and Climate Bonds Initiative (2017) study the difference in yield at issuance between a green bond and a conventional bond by calculating the difference between the two yields for samples of 30 and 14 bonds, respectively. These two works do not find any significant differences on the primary market, which confirms the analyses conducted in OECD (2017b) and I4CE (2016) showing that investors are not willing to pay a premium to acquire a green bond at issuance ("flat pricing"). Barclays (2015) and Bloomberg (2017) focus on the yield differential on the secondary market. Through an OLS regression of the

[7] The ICMA recently published voluntary guidelines for issuing *social bonds*, which are a nascent asset class: https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/June-2018/Social-Bond-Principles---June-2018-140618-WEB.pdf.

[8] Luo and Bhattacharya (2009) clarify the difference between corporate social responsibility (CSR) and CSP: CSP (i) refers to stakeholders' assessment of the quality of CSR investments, (ii) can be a proxy for a firm's cumulative involvement in CSR and (iii) is a notion relative to the competition in the industry.

[9] According to the Forum for Sustainable and Responsible Investment, "Sustainable, responsible and impact investing (SRI) is an investment discipline that considers environmental, social and corporate governance (ESG) criteria to generate long-term competitive financial returns and positive societal impact." (https://www.ussif.org/sribasics , answer to the question "What is sustainable, responsible and impact investing?"). Investments with a positive environmental impact (or *good environmental performance*) are therefore a form of sustainable investment for which the expected benefits specifically concern the environment.

[10] Dhaliwal et al. (2011) focus on the initiation of a voluntary disclosure of CSR activities and show that it leads to a reduction in a firm's cost of capital.

Table 1
Research methods and findings on green bond pricing. This table summarizes the research methods and empirical findings of studies on the relative pricing of green bonds in relation to conventional bonds.

	Barclays (2015)	HSBC (2016)	Bloomberg (2017)	Climate Bonds Initiative (2017)
Green bonds (Alignment with the GBP)	Yes	Yes	Yes	Yes
(a) Literature prior to this paper.				
Scope	Global	Euro and US	European Investment Bank, Nordic Investment Bank and International Bank for Reconstruction and Development	EUR- and USD-denominated Govt.-related and corporate bonds
Primary / Secondary market	Secondary	Primary / Secondary	Secondary	Primary
Number of bonds	N.A.	30 / 4	12	14
Time period	Mar. 2014 - Aug. 2015	Nov. 2015 - Sep. 2016	Mar. 2014 - Dec. 2016	Jan. 2016 - Mar. 2017
Method	OLS regression	Comparison	Comparison	Comparison
Liquidity control	Date of issuance	No	No	No
Strict maturity control	No	No	No	No
Yield premium	−17bps	No	EUR-denominated Govt.-related bonds: -25ps USD-denominated and corporate bonds: No	No
	Ehlers and Packer (2017)	Karpf and Mandel (2018)	Baker et al. (2018)	Hachenberg and Schiereck (2018)
Green bonds (Alignment with the GBP)	Yes	No	No	Yes
(b) Literature subsequent to and building on this paper.				
Scope	Euro and US	US Municipal bonds with a Bloomberg green flag	US Corporate and Municpal bonds with a Bloomberg green flag	Global
Primary / Secondary market	Primary	Secondary	Primary	Secondary
Number of bonds	21	1880	2083	63
Time period	2014–2017	2010–2016	2010–2016	Oct. 2015 - March. 2016
Method	Comparison	Oaxaca-Blinder decomposition	OLS regression	Matching + panel regression based on our paper's method
Liquidity control	No	Number of transactions within the past 30 days	Issue amount	Issue amount
Strict maturity control	Yes	Yes	Yes	Yes
Yield premium	−18 bps	+7.8 bps	−7 bps	−1 bp

credit spread on several market risk factors, Barclays (2015) points to a negative premium of 17 bps between March 2014 and August 2015. By analyzing 12 bonds between March 2014 and December 2016, Bloomberg (2017) highlights a negative 25 bps premium on EUR-denominated government-related bonds but does not identify any premium on USD-denominated and corporate bonds.

Subsequent works have built on the first version of this paper (Ehlers and Packer, 2017; Karpf and Mandel, 2018; Hachenberg and Schiereck, 2018; Baker et al., 2018). Ehlers and Packer (2017) and Hachenberg and Schiereck (2018) study samples of 21 and 63 green bonds aligned with the Green Bond Principles, respectively. Ehlers and Packer (2017) focus on the primary market between 2014 and 2017, whereas Hachenberg and Schiereck (2018) analyze the secondary market over 6 months between 2015 and 2016 using a matching procedure and a panel regression based on the methodology of our paper. Both papers find a negative premium but of very different magnitudes: -18 bps for the former and -1 bp for the latter. Karpf and Mandel (2018) and Baker et al. (2018) study a less restrictive framework than that of green bonds aligned with the Green Bond Principles: U.S. bonds with a Bloomberg green flag. Karpf and Mandel (2018) focus on municipal bonds on the secondary market, and Baker et al. (2018) analyze municipal and corporate bonds on the primary market. By controlling bonds' liquidity through the number of transactions within the past 30 days, Karpf and Mandel (2018) find a positive premium of 7.8 bps. In contrast, using the issue amount as a proxy of the liquidity, Baker et al. (2018) find evidence of a 7 bps negative premium.

Existing works on the relative valuation of green bonds aligned with the Green Bond Principles therefore suffer from both a limited scope of analysis as well as imperfect control of the liquidity premium, leading to mixed results. This paper aims to estimate the fair yield of green bonds compared to that of conventional bonds over an extensive scope, ensuring that all the discrepancies between the two types of bonds are duly controlled.

3. Data description and matching method

The empirical method primarily used in the CSR literature to analyze bond spreads consists in performing an appropriate regression on a suitable specification. This step requires determining the financial and extra-financial independent variables likely to explain the intrinsic value of the bond spread as exhaustively as possible while ensuring the robustness of the specification. Analyzing the yield of a green bond allows us to forgo this method because we can match two similar bonds from the same issuer, for which most of the factors explaining the yield are identical. We therefore use a matching method, also known as a model-free approach or a direct approach, which is a useful technique for analyzing the intrinsic value of a specialized financial instrument. This method consists of matching a pair of securities with the same properties except for the one property whose effects we are interested in. This method has been used to assess the additional return of ethical funds in comparison with identical conventional funds or indices (Kreander et al., 2005; Renneboog et al., 2008; Bauer et al., 2005) as well as the cost of liquidity by matching and comparing pairs of bonds issued by the same firm (Helwege et al., 2014).

We set up this database to evaluate the yield spread between a green bond and an equivalent synthetic conventional bond. For this purpose, we take matched pairs consisting of a green and a conventional bond with identical characteristics except for their liquidity. The variable construction procedure used here is closely related to that used by Helwege et al. (2014) to assess the effects of liquidity on corporate bond spreads. However, while building on the latter study, we add a new parameter–the greenness of a bond: determining the impact of this parameter on the bond yield is the goal of our assessment. The difference between the green bond yield and the equivalent synthetic conventional bond yield is therefore precisely the cumulative effect of the liquidity differential and the green bond premium.

We examine the entire sample of 1065 green bonds complying with the Green Bond Principles indexed by Bloomberg on December 31, 2017. This set includes bonds of various kinds: supranational, sub-sovereign and agency (SSA), municipal, corporate, financial and covered bonds. To build this synthetic conventional bond, for each green bond, we first search for the two conventional bonds with the closest maturity from the same issuer and having exactly the same characteristics: they all have the same currency, rating,[11] bond structure, seniority, collateral and coupon type. Since the maturities cannot be equal, we collect conventional bonds with a maturity that is neither two years shorter nor two years longer than the green bond's maturity. The difference in maturity is limited in this way to estimate more accurately the equivalent synthetic conventional bond yield in the next stage. The other difference between the two categories of bonds is their liquidity, which can be assessed from either their issue amount or their issue date (see Bao et al., 2011; Houweling et al., 2005). A substantial difference in liquidity can have a notable effect on the yield level and must therefore be limited.[12] Here again, to ensure a fair approximation in this first stage, we combine a double constraint on the difference in liquidity: we restrict the eligible conventional bonds to those (i) with an issue amount of less than four times the green bond's issue amount and greater than one-quarter of this amount (Table A1) and (ii) with an issue date that is, at most, six years earlier or six years later than the green bond's issue date[13] (see Fig. A1). This double restriction in the matching method allows us to better control for any residual liquidity bias in the estimation step of the green bond premium (see Section 4.1). Any green bonds for which fewer than two of the corresponding conventional bonds comply with these requirements is excluded from the database.

In a second stage, the maturity bias is eliminated by building a panel composed of pairs of bonds: an equivalent synthetic conventional bond with the same maturity is assigned to each green bond. The ask yields of each triplet of bonds (the green bond and the two corresponding conventional bonds) are retrieved from the issue date of the green bond up to December 31, 2017. The source used for this purpose is Bloomberg BGN[14], which provides end-of-day market prices and yields based on multiple contributors' market prices as well as all the characteristics of the bonds. As green bonds are not all listed in TRACE, we cannot take advantage here of the richness of this source, especially with respect to the volumes traded. Since this study focuses on the investors' demand and the issuers' supply of green bonds, we focus on the ask yields of each triplet for a more precise analysis. If, on a specific day, at least one of the three ask yields is not available, we remove the line from our panel. We then interpolate (or extrapolate) the two conventional bonds' yields linearly at the green bond maturity date to obtain a synthetic conventional bond yield, which thus shows the same properties as the green bond except for the difference in liquidity. Practically, for each triplet, with a^* the slope and b^* the intercept of the affine function passing through (Maturity_{CB1}, y^{CB1}) and (Maturity_{CB2}, y^{CB2}), the yield of the synthetic conventional bond is $\tilde{y}^{CB} = a^*\text{Maturity}_{GB} + b^*$ (see Fig. A2). Because of the linear interpolation (or extrapolation), this method differs slightly from that used in Helwege et al. (2014), in which the closest bond is selected, which gives rise to a tiny maturity bias. The constitution of the database is finalized by defining the yield spread between the green bond and the equivalent synthetic conventional bond. Let $y^{GB}_{i,t}$ and $\tilde{y}^{CB}_{i,t}$ be the green bond and the conventional bond i's ask yields, respectively, on day t. We take $\Delta\tilde{y}_{i,t} = y^{GB}_{i,t} - \tilde{y}^{CB}_{i,t}$.

This approach enables us to remove all the unobservable factors common to both bonds in the matched pairs and to significantly reduce the liquidity bias. The process leaves us with 110 matched green bonds accounting for 10% of the global green bond universe and 17% of the total outstanding green bond debt. All of the bonds in our sample are senior, bullet, fixed-coupon bonds. Except for one BB and 12 non-rated, all of them are investment-grade bonds. Significant variations are observed in the yield levels, notably between the various issue currencies, i.e., across the corresponding rate and credit curves (see Table 2). For example, while the average AAA government-related green bond yield in Turkish lira is 10.28%, it only amounts to 0.26% in the same market segment for the bond labeled in EUR.

The sample comprises a 37,503-line unbalanced bond-day panel in which the earliest information dates back to July 18, 2013, and the latest is dated December 29, 2017. For the sample, the statistics of the green and conventional bonds' yields, maturities and issue amounts are presented in Table 3.

Upon focusing on the time average difference in yield ($\Delta\tilde{y}_i$), the distribution across bonds is found to be skewed to the left: There are 63% negative values, giving an average of −2 bps[15] and a median value of −1 bp. In the next section, we will therefore study $\Delta\tilde{y}_{i,t}$ to determine whether there is a premium attributable to the greenness of a bond.

4. Empirical methodology

4.1. Step 1: Estimation of the green bond premium

The first step of the empirical methodology aims at controlling for the residual difference in liquidity between both bonds of each pair and estimating the green bond premium. We therefore design a variable, $\Delta\text{Liquidity}_{i,t}$, capturing the difference in liquidity and defined as the difference between a green bond and a conventional bond's liquidity indicator:

$$\Delta\text{Liquidity}_{i,t} = \text{Liquidity}^{GB}_{i,t} - \text{Liquidity}^{CB}_{i,t} \tag{1}$$

The green bond premium p_i is therefore defined as the unobserved effect in the fixed-effects panel regression of $\Delta\tilde{y}_{i,t}$ on $\Delta\text{Liquidity}_{i,t}$:

[11] Since an institution can issue various bonds of different kinds or seniority levels and, thus, with different ratings, we make sure that the rating is the same.

[12] It is widely agreed that bond credit spreads incorporate a positive illiquidity premium (see for example Chen et al., 2007; Beber et al., 2009; Bao et al., 2011; Dick-Nielsen et al., 2012; de Jong and Driessen, 2012).

[13] Authors controlling for the difference in liquidity solely through the date of issuance suggest different levels, from 1 year (Elton et al., 2004) to 2 years (Alexander et al., 2000; Houweling et al., 2005). In this paper, we combine three different liquidity controls (two in the matching method and one in the estimation process), with less stringent restrictions for the first two controls, to enable a closer maturity matching and a wider sample. We verify in the robustness checks (Section 6) that these liquidity controls are acceptable. Furthermore, Wulandari et al. (2018) find that the impact of illiquidity on green bonds' yield spread has become negligible in most recent years.

[14] We voluntarily exclude Bloomberg BVAL prices that combine market data with model pricing.

[15] Note that one cannot infer the −2-bps average yield difference with y^{GB} and $\tilde{y}^{CB}$ because the average in i of the average in t of the yield differences is not equal to the yield difference on the average in i of the average in t of the green bonds' yields and the conventional bonds' yields. The same applies to the medians and quartiles.

Table 2
Description of the sample of 110 green bonds. This table shows the average yield and maturity of the sample of 110 green bonds, broken down by sector, rating, and currency.

		AUD	CAD	CHF	CNY	EUR	GBP	INR	JPY	RUB	SEK	TRY	USD	Total
Basic Materials														
NR	Average yield (%)										0.96			0.96
	Average maturity (years)										4.74			4.74
	Nb. of GB										1			1
Consumer, Non-cyclical														
BBB	Average yield (%)					0.78								0.78
	Average maturity (years)					5.51								5.51
	Nb. of GB					1								1
Financial														
AAA	Average yield (%)	2.43				0.07	0.79				0.10		1.98	0.83
	Average maturity (years)	2.50				4.94	2.43				2.96		3.52	4.13
	Nb. of GB	1				10	1				1		6	19
AA	Average yield (%)	3.00				0.28							2.10	1.11
	Average maturity (years)	3.37				5.68							2.70	4.86
	Nb. of GB	3				8							1	12
A	Average yield (%)				3.70	0.36					0.77		2.17	1.34
	Average maturity (years)				0.53	4.25					4.13		1.98	3.09
	Nb. of GB				1	8					2		8	19
BBB	Average yield (%)					0.61							3.65	2.13
	Average maturity (years)					4.49							2.92	3.70
	Nb. of GB					1							1	2
BB	Average yield (%)												5.23	5.23
	Average maturity (years)												3.38	3.38
	Nb. of GB												1	1
NR	Average yield (%)										0.66			0.66
	Average maturity (years)										2.77			2.77
	Nb. of GB										11			11
Government														
AAA	Average yield (%)	2.41	1.57	0.03		0.26	0.59	5.70		6.65	0.49	10.28	1.73	1.92
	Average maturity (years)	1.33	2.85	7.10		5.54	2.18	3.15		1.57	4.75	1.24	3.15	3.50
	Nb. of GB	1	2	1		3	1	1		1	4	1	15	30
AA	Average yield (%)			0.31									2.16	1.23
	Average maturity (years)			11.92									1.64	6.78
	Nb. of GB			2									2	4
A	Average yield (%)								0.39					0.39
	Average maturity (years)								14.79					14.79
	Nb. of GB								3					3
BBB	Average yield (%)												2.68	2.68
	Average maturity (years)												2.25	2.25
	Nb. of GB												1	1
Industrial														
BBB	Average yield (%)					0.83								0.83
	Average maturity (years)					5.94								5.94
	Nb. of GB					1								1
Utilities														
A	Average yield (%)					0.49								0.49
	Average maturity (years)					2.85								2.85
	Nb. of GB					2								2
BBB	Average yield (%)					0.94								0.94
	Average maturity (years)					6.41								6.41
	Nb. of GB					3								3
	Average yield	2.77	1.57	0.22	3.70	0.34	0.69	5.70	0.39	6.65	0.62	10.28	2.09	1.31

$$\Delta\tilde{y}_{i,t} = p_i + \beta\Delta\text{Liquidity}_{i,t} + \epsilon_{i,t}, \text{ with } \epsilon_{i,t} \text{being the error term} \quad (2)$$

Given the data sources and the type of regression, the liquidity proxies that can be used here are subject to three constraints. Firstly, since we cannot use intraday data to calculate intraday liquidity indicators, such as the Amihud measure (Amihud, 2002), Range measure (Han and Zhou, 2016) or intraday Roll and Gamma measure (Roll, 1984; Bao et al., 2011), for example, we focus on low-frequency data. Secondly, in constrast to what can be done with the TRACE database, we do not have any information about the daily trading volumes that might have been used as liquidity proxies (Beber et al., 2009; Dick-Nielsen et al., 2012). Thirdly, to ensure the full rank condition of a *within* regression, any variable that does not change over time with a given bond is not suitable. Proxies such as the issue amount, the issue date or off-the-run versus on-the-run indicators (Bao et al., 2011; Houweling et al., 2005) therefore cannot be used.

We take the closing percent quoted bid-ask spread as a proxy of the liquidity, consistent with Fong et al. (2017), who show, through an extensive analysis of the quality of high- and low-frequency liquidity proxies, that it is the best low-frequency liquidity proxy. Indeed, bid-ask spread has been widely used as a major measure of the degree of illiquidity of a bond (see Beber et al., 2009; Dick-Nielsen et al., 2012; Chen et al., 2007).

Since the synthetic conventional bonds are based on the two closest conventional bonds, the conventional bond's bid-ask spread is defined as the distance-weighted average of CB1's and CB2's bid-ask spreads. In practical terms, let $d_1 = |\text{Green Bond maturity - CB1 maturity}|$ and

Table 3
Descriptive statistics of the bonds in the sample. This table gives the distribution of several variables of interest in all 110 triplets of bonds in our sample. The number of days per bond is the length of the time series per pair of bonds since their inception. The distribution of the ask yield is presented for green bonds (y^{GB}), the two closest conventional bonds (y^{CB_1} and y^{CB_2}) and the interpolated (or extrapolated) conventional bonds ($\tilde{y}^{CB}$). The difference in yield ($\Delta\tilde{y}_{i,t}$) is the difference between the green bonds' ask yield and the interpolated (or extrapolated) conventional bonds' ask yield. To compare the accuracy of the interpolations (or extrapolations), this table also shows the distribution of maturities and the issue amounts of the green bonds and the two closest conventional bonds.

	Sample					
	Min.	1st Quart.	Median	Mean	3rd Quart.	Max
Number of days per bond	12	99	306	341	518	1 150
Ask yield of the GB (y^{GB})	− 0.35	0.26	0.92	1.31	1.90	10.28
Ask yield of the interp. CB ($\tilde{y}^{CB}$)	− 0.43	0.27	0.94	1.33	1.92	10.19
Ask yield of the CB1 (y^{CB1})	− 0.34	0.22	0.88	1.29	1.98	10.17
Ask yield of the CB2 (y^{CB2})	− 0.33	0.24	0.81	1.25	1.95	10.28
Yield difference % ($\Delta\tilde{y}_{i,t}$)	− 0.46	− 0.03	− 0.01	− 0.02	0.01	0.10
Green bond maturity on Dec. 30, 2017 (years)	0.14	2.20	3.45	4.15	4.87	29.74
Conventional bond 1 maturity	0.07	1.86	3.29	4.03	4.72	28.99
Conventional bond 2 maturity	0.26	1.82	3.11	3.79	4.93	28.23
Green bond issue amount (USD bn)	0.01	0.30	0.50	0.65	0.80	3.60
Conventional bond 1 issue amount	0.01	0.32	1.00	1.34	1.48	7.20
Conventional bond 2 issue amount	0.01	0.28	0.90	1.24	1.24	7.48

Table 4
Descriptive statistics of the liquidity proxy ΔBA. This table summarizes the distribution of the liquidity control: ΔBA is the difference between the green bonds' bid-ask spread and the conventional bonds' distance-weighted average bid-ask spread, in a specific pair of bonds, during the period under consideration.

	Min.	1st Quart.	Median	Mean	3rd Quart.	Max	Std. Dev.
ΔBA	−0.436%	−0.021%	0.000%	0.006%	0.032%	0.758%	0.11%

$d_2 = |$Green Bond maturity - CB2 maturity$|$. The synthetic conventional bond's bid-ask spread is therefore as follows:

$$\mathrm{BA}_{i,t}^{CB} = \frac{d_2}{d_1 + d_2}\mathrm{BA}_{i,t}^{CB1} + \frac{d_1}{d_1 + d_2}\mathrm{BA}_{i,t}^{CB2} \tag{3}$$

$\Delta\mathrm{BA}_{i,t} = \mathrm{BA}_{i,t}^{GB} - \mathrm{BA}_{i,t}^{CB}$ is consequently the independent variable used in Eq. (2) to estimate the fixed-effects linear panel.

Table 4 show that ΔBA is concentrated around zero and has a low standard deviation. This condition indicates that the first liquidity controls on the issue amount and the date of issuance in the matching method yielded acceptable results.

We use a *within* regression to estimate the fixed effects p_i in Eq. (2) for various reasons. Firstly, we want to bring out the bond-specific time-invariant unobserved effect without imposing any distribution or using any information about the other bonds. Secondly, these data do not hold for a broader category but, rather, give the characteristics of a specific bond. From the technical point of view, strict exogeneity holds and ensures unbiasedness and consistency of the estimator. Finally, the fact that we do not require the difference in liquidity proxy to be uncorrelated with the unobserved specific effects provides for a wide range of potential control parameters.

Several individual effect tests and a Hausman test are performed to check the efficiency of the fixed-effects estimator. Moreover, controlling the difference in yield by the difference in liquidity prevents the occurrence of any simultaneity effects: the difference between two yields does not have any retroactive effect on the liquidity of the bonds. Lastly, various robustness tests are performed and, to address the loss of efficiency due to heteroscedasticity and serial correlation, we use the Newey-West and Beck-Katz robust estimations of the standard errors.[16]

4.2. Step 2: The determinants of the green premium

In the first step, we isolated the yield premium of a green bond linked to the specific nature of the debt security. The second step highlights the determinants of the green bond premium since it may not be stable across bonds. We therefore consider the characteristics through which bonds differ to determine where, and to what extent, the premium applies. The variables considered are the rating, the sector, the currency, the maturity and the issue amount of the green bond. Table 5 provides details on the variables and their construction.

After performing robustness tests, we estimate several cross-sectional specifications, including the main specification described in the following equation, through an OLS regression with robust estimation of the standard errors. Taking η_i to denote the error term, we set the following:

$$\begin{aligned}\widehat{p_i} = \alpha_0 &+ \sum_{j=1}^{N_{rating}-1} \alpha_{1,rating_j} 1_{rating_j} + \sum_{j=1}^{N_{sector}-1} \alpha_{2,sector_j} 1_{sector_j} \\ &+ \sum_{j=1}^{N_{currency}-1} \alpha_{3,currency_j} 1_{currency_j} \\ &+ \alpha_4 \mathrm{Maturity} + \alpha_5 log(\mathrm{Issue\ Amount}) + \eta_i\end{aligned} \tag{4}$$

We take the logarithm of the issue amount to linearize the values of the variable that can be interpolated by an exponential function. Moreover, as an alternative to having the variables represent rating and sector, we also consider the dummy variables that capture rating $\times$ sector cross effects because descriptive statistics

[16] The results are robust to performing a Fixed Effects Generalized Least Squares regression: the estimated premia are equal to those estimated with a Fixed Effects Ordinary Least Squares (*within*) regression by a factor of 0.1 bps. Since the number of bonds studied is lower than the average number of days and for the sake of simplicity, we present here the results of the Fixed Effect OLS regression with robust estimation of the standard errors.

Table 5
Description of the independent variables of the step 2 regression. This table provides details about the independent variables used in the step 2 regression, namely, their type, unit and description.

Variable	Type	Unit	Description
Rating	Qualitative		The rating of the bond can be AAA, AA, A, BBB, BB or Non-rated (NR) in our sample. The reference value is AAA. To attribute a single rating to the bond, the following procedure is used. The issuer ratings of the three agencies S&P, Moody's and Fitch are rounded off by removing the potential + or - . We then take the majority rating among those available. If there are only two different ratings available, we take the highest one.
Sector	Qualitative		We use the level 1 Bloomberg classification (BICS level 1) for the issuer-type breakdown procedure, which leaves us, in the case of the present sample, with six categories: (i) *Basic Materials*; (ii) *Consumer, Non-cyclical*; (iii) *Financials*, which encompasses non-public banks and financial services; (iv) *Government*, also referred to as *Government-related*, which includes public institutions, municipalities, regional and sovereign agencies, and national, supranational and development banks; (v) *Industrial*; and (vi) *Utilities*. The reference value is *Government*.
Currency	Qualitative		The currency of the bond issuance. In our sample, the referenced currencies are as follows: AUD, CHF, EUR, JPY, SEK, USD, CAD, RUB, GBP, TRY, CNY and INR. The reference level is the USD. See the online appendix for the meaning of each acronym.
Maturity	Quantitative	Years	The maturity of the bond on December 31, 2017.
Issue Amount	Quantitative	bn USD	The issue amount of the green bond considered December 31, 2017.

indicate that this segmentation may promote the variation of the premium.

5. The green bond premium

5.1. A small, albeit significant, negative green bond premium

The first step in the analysis aims to estimate the green bond premium, including its significance, sign and magnitude. We confirm the presence of an unobserved heterogeneous effect via an F-test, a Wooldridge test, a Breusch–Pagan test and a Honda test.[17] We also conduct a Hausman test that indicates that the fixed-effects within estimator is more robust than the random-effect estimator. The within estimator is unbiased and consistent: although it is intuitive that the idiosyncratic error term may not be correlated with either the previous or future differences in liquidity (neither feedback effect nor financial periodicity), we confirm the strict exogeneity hypothesis through Su et al. (2016)'s test.[18] This estimation is all the more satisfactory as the average number of days is higher than the number of bonds (see Goldstein, 2003) and $\Delta BA_{i,t}$ varies substantially with time.

Moreover, we run Breusch–Godfrey, Durbin Watson, and Wooldridge tests, all of which indicate the existence of serial correlation. In addition, a Breusch–Pagan test shows the presence of heteroscedasticity. To account for heteroscedasticity and serial correlation, we complement the regression with Newey–West and Beck–Katz[19] robust estimations of the standard errors.

Although the regression evidences a weak R^2 equal to 1%, the bid-ask spread differential used to control for the difference in liquidity proves to be highly significant for the three different estimators of the standard errors (Table 6). Although small in the present case, the residual liquidity differential has significant explanatory power and the step used for its control should not be discarded, *a fortiori* in situations in which the matching constraints are less stringent and because it is useful for developing a general method. Thus, a 1-bp increase in the percentage price bid-ask spread differential induces a 9.88-bps decrease in $\Delta\tilde{y}_{i,t}$.

The value of the 110 fixed-effects p_i constituting each of the green bonds' premia is more important for the present purposes. The distribution ranges from −38 bps to +10 bps with a mean and a median value of −1.76 bps and −1.04 bps, respectively (Table 7). A total of 63% of the premia are negative, and the amplitudes are greater on the downside than on the upside (Fig. 1). It is worth noting that the extreme values of $\widehat{p_i}$ appear for currencies presenting a high yield (such as INR, RUB or TRY).

Lastly, we break down the sample in several subsamples by the main characteristics of the bond: its rating, sector and currency. We calculate the average premium by subsample and test whether it is significantly different from zero for subsamples with at least ten bonds. Through a Shapiro–Wilk normality test, we reject the normality hypothesis for all subsamples except AA bonds and SEK-denominated bonds. We therefore use the non-parametric Wilcoxon signed-rank test, which is applied to our specific framework,[20] to assess the significance of the premia per subsample. The results are robust to a test under the hypothesis of normality for A and SEK-denominated bonds.

Table 6
Results of the step 1 regression. This table gives the results of the step 1 regression: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta BA_{i,t} + \epsilon_{i,t}$. In addition to a classical within regression, Newey–West and Beck–Katz robust standard error tests are performed.

	Dependent variable: $\Delta\tilde{y}_{i,t}$		
	Within	Newey–West robust std. err.	Beck–Katz robust std. err.
ΔBA	− 9.881***	− 9.881***	− 9.881***
	(0.440)	(2.774)	(3.334)
Observations		37,504	
R^2		0.013	
Adjusted R^2		0.010	
F Statistic		504.125***	
		(df = 1; 37393)	

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Table 7
Distribution of the estimated green bond premia. This table summarizes the distribution of the estimated green bond premia in our full green bond sample, i.e., the fixed effect of the following regression: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta \mathrm{Liquidity}_{i,t} + \epsilon_{i,t}$.

$\hat{p}_i$ (%)					
Min.	1st Quart.	Median	Mean	3rd Quart.	Max
−0.381	−0.029	− 0.01	−0.018	0.008	0.100

[17] See the online appendix for the details of the tests performed.

[18] We test strict exogeneity for a two-day lag and lead period. The P-value is equal to 73.1%.

[19] Beck and Katz (1995) prove that their robust estimator performs well in small panels.

[20] For a subsample of n premia, the test is built as follows. We rank the n premia in ascending order of their absolute value and assign them a rank, R, from 1 to n. Let *sgn* represent the sign of the premium; we consider the following statistic:

$$W = \sum_{i=1}^{n} sgn(\widehat{p_i})R_i$$

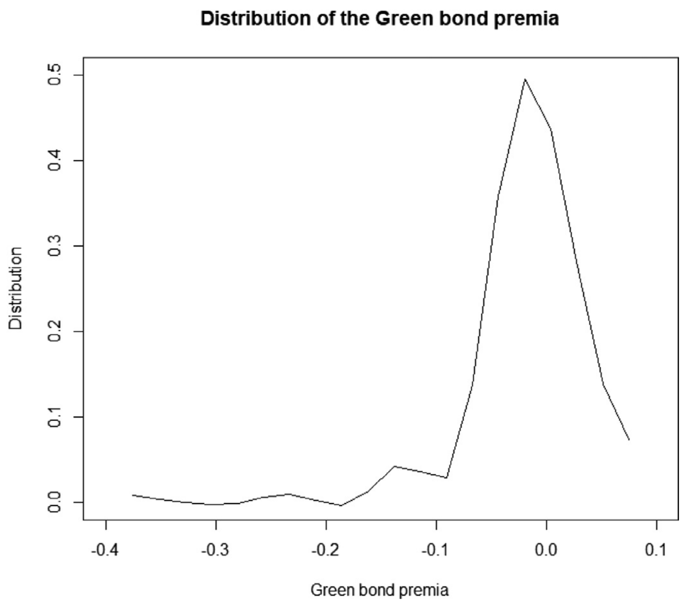

Fig. 1. Green bond premia distribution. This figure gives the distribution of the green bond premia $\widehat{p}_i$ across all bonds included in this study.

Table 8
Green bond premia in several market segments. This table shows the mean and median green bond premia in several market segments, the level of significance at which we rejected $H_0 : \widehat{p}_i = 0$, and the number of green bonds in each of the subsamples. We use a Wilcoxon signed-rank test with continuity correction.

		Mean($\widehat{p}_i$)	Median($\widehat{p}_i$)	$\widehat{p}_i \neq 0$	# GB
Total		−0.018	−0.010	***	110
Sector	Basic Materials	−0.016	−0.016		1
	Consumer, NC	−0.011	−0.011		1
	Financial	−0.025	−0.013	***	64
	Government	−0.009	0.000		38
	Industrial	0.005	0.005		1
	Utilities	0.002	−0.003		5
Currency	AUD	−0.031	−0.019		5
	CAD	−0.010	−0.010		2
	CHF	0.000	0.001		3
	CNY	0.024	0.024		1
	EUR	−0.017	−0.011	**	37
	GBP	−0.001	−0.001		2
	INR	0.055	0.055		1
	JPY	0.033	0.051		3
	RUB	−0.381	−0.381		1
	SEK	−0.009	−0.007		19
	TRY	0.079	0.079		1
	USD	−0.023	−0.019	***	35
Rating	AAA	−0.010	−0.003		49
	AA	−0.029	−0.024	***	16
	A	−0.018	−0.011		24
	BBB	−0.021	−0.009		8
	BB	−0.206	−0.206		1
	NR	−0.012	−0.007		12

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 8 shows the average and median premia per subsample. The −1.8-bp average premium on the entire sample is significantly different from zero at a 99% level of confidence. Financial green bonds carry a −2.3-bps average premium with the same degree of significance. EUR-denominated and USD-denominated green bonds also have a significant negative premium of −1.7 bp and −2.3 bps, respectively. Lastly, AA green bonds show a −2.9-bps premium. Although the average and median premia of the other categories are not significantly different from zero, most of them are negative.

The literature analyzing the liquidity of off-the-run vs. on-the-run bonds highlights a significant liquidity premium of approximately 1.5 bp on U.S. Treasury bonds with the same characteristics except for their issue date. The comparison can be of interest because this premium affects bonds from the same issuer that have the same characteristics except for their issue date and, therefore, their degree of liquidity. By matching 55 pairs of bonds between 1994 and 2000, Goldreich et al. (2005) show a yield differential of 1.5 bp between off-the-run and on-the-run US Treasury bonds. Pasquariello and Vega (2009) also find a yield difference of 1.6 bp on 5-year U.S. Treasury bonds by matching 86 bonds over the period 1992–2000.

We therefore provide evidence that investors in the secondary market pay a small negative yield premium inherent to green bonds, which is of a magnitude comparable to that of the on-the-run liquidity premium on U.S. Treasury bonds.

5.2. The determinants of the green bond premium

To determine and evaluate the determinants of a green bond premium, a linear regression of $\widehat{p}_i$ is performed on the characteristics of the green bonds. Table 9 shows the four regression specifications considered: (a) represents the most general specification, based on Eq. (4); (b) excludes the variables *Maturity* and *log(Issue Amount)*; (c) further excludes the currency dummies and the independent variables; and (d) represents solely the Rating × Sector cross effects. To avoid artificially high R^2s, the four regressions are performed on samples in which each of the dummy variables captures more than three observations. The R^2s therefore range from 11.3% (d) to 14.1% (a). The regression on the entire sample, of which the results are in line with that on restricted samples, is shown in Appendix (Table A2) and has an R^2 equal to 60.6%. Since the results of the Breusch-Pagan test evidence the presence of heteroscedasticity for the first three specifications,[21] we estimate White robust standard errors. Besides, the VIF calculation does not lead to a suspicion of multicollinearity.

Specifications (a) and (b) show that neither the maturity, the issue amount, nor the currency has a significant impact on the level of the premia in the considered subsample. The first two conclusions hold for the regression on the entire sample (Table A2); however, although the number of observations is limited, we suspect that the currency involved may have an impact in less mature financial markets. Specifications (a), (b), and (c) show that the rating significantly affects the premium: the lower the rating of the green bond is, the lower the green premium. The effect is particularly significant for AA and A bonds, with both values −2.3 bps with respect to AAA bonds (specification (b)). The study of Rating × Sector cross effects (specification (d)) shows that the level of premia varies between government-related bonds and financial bonds: while the negative impact of a lower rating is maintained in both sectors, the premia on financial bonds (-2.7 bps and -2.5 bps for AA and A, respectively) are lower than those on government-related bonds (−1.7 bps for AA).

These findings can be linked with the literature on the liquidity premium. Similar to the liquidity premium, the green bond premium fades with the increase of the credit quality (Longstaff et al., 2005; Chen et al., 2007; Bao et al., 2011; Dick-Nielsen et al., 2012; Huang and Huang, 2012; Abudy and Raviv, 2016). In addition, the absolute value of the negative green bond premium is greater for financial bonds, similar to the situation regarding the liquidity premium (Longstaff et al., 2005). However, contrary to the liquidity premium, which increases for low issue amounts (Longstaff et al.,

Under the null hypothesis H_0: $\widehat{p} = 0$, with $\sigma_w = \sqrt{\frac{n(n+1)(2n+1)}{6}}$, $\frac{W \pm 0.5}{\sigma_w}$ converges to a normal distribution. We add (subtract, resp.) 0.5 if $W < 0$ ($W > 0$, resp.) as a *continuity correction* since we compare discrete data to a continuous probability function.

[21] See the online appendix for the details of the tests performed.

Table 9
Results of step 2 regressions. This table gives the results of step 2 regressions in which the green bond premium is explained by the characteristics of the bonds through specifications (a),(b), (c), and (d). The premium is expressed as a percentage. The rating is a qualitative variable, the four modalities of which are AAA (reference modality), AA, A, and BBB. Maturity is the maturity of the bond expressed in years on December 31, 2017. The issue amount is the amount of green bonds issued expressed in USD billions. Sector is a qualitative variable, of which the three modalities are Government (reference modality), Financials and Utilities. We also consider Rating × Sector cross effects. Currency is a qualitative variable, of which the four modalities are USD (reference modality), AUD, EUR, and SEK.

	Dependent variable: $\widehat{p}_i$			
	Cross-sectional regressions with White robust standard errors			
	(a)	(b)	(c)	(d)
Constant	−0.003	−0.004	−0.002	−0.007
	(0.015)	(0.010)	(0.009)	(0.009)
Rating AA	−0.025**	−0.023**	−0.024**	
	(0.010)	(0.010)	(0.010)	
Rating A	−0.026*	−0.023*	−0.022*	
	(0.014)	(0.013)	(0.013)	
Rating BBB	−0.043	−0.040	−0.041	
	(0.043)	(0.041)	(0.040)	
Non-rated	−0.018	−0.009	−0.001	
	(0.020)	(0.018)	(0.014)	
Sector Financial	−0.008	−0.009	−0.008	
	(0.012)	(0.012)	(0.012)	
Sector Utilities	0.039	0.035	0.037	
	(0.034)	(0.032)	(0.031)	
AA × Government				−0.017*
				(0.009)
AAA × Financial				0.004
				(0.011)
AA × Financial				−0.027**
				(0.013)
A × Financial				−0.025*
				(0.013)
NR × Financial				−0.005
				(0.015)
Currency AUD	−0.009	−0.006		
	(0.014)	(0.013)		
Currency EUR	0.009	0.004		
	(0.010)	(0.010)		
Currency SEK	0.004	0.010		
	(0.016)	(0.011)		
Maturity	−0.001			
	(0.002)			
log(Issue Amount) (bn USD)	−0.006			
	(0.009)			
Observations	92	92	92	84
R^2	0.141	0.134	0.127	0.113
Adjusted R^2	0.023	0.039	0.066	0.056
Residual Std. Error	0.041 (df = 80)	0.041 (df = 82)	0.040 (df = 85)	0.038 (df = 78)
F Statistic	1.195 (df = 11; 80)	1.411 (df = 9; 82)	2.064* (df = 6; 85)	1.987* (df = 5; 78)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

2005), the green bond premium does not seem to be affected by low issue amounts. Moreover, Driessen et al. (2016) find liquidity segmentation between long- and short-dated bonds, and Ejsing et al. (2012) and Schuster and Uhrig-Hombourg (2012) show that the liquidity premium is greater in the short term. The green bond premium, in contrast, does not appear to be significantly impacted by the maturity of the bond.

Focusing on specification (b), we can express the green bond premia in absolute terms: they increase as the rating improves and are lower for financial bonds. For example, the yield of an AAA, AA, A and BBB EUR financial green bond is lower than that of an equivalent conventional bond by 0.9 bps, 3.2 bps, 3.2 bps and 4.9 bps, respectively. However, the yields of green and conventional AAA government-related bonds are in line (0 bp for EUR and -0.4bp for USD). As for the EUR (USD, resp.) utilities, although not significantly different from zero, the average premium is +1.2 bps (+0.8 bps, resp.) for A-green bonds and −0.5 bps (−0.9 bps, resp.) for BBB-green bonds.

These findings nuance several previous works that addressed this issue. We show that the yield differential between green and conventional bonds is negative for financial bonds–which are the most active corporate issuers–as suspected by Barclays (2015) and Ehlers and Packer (2017). Nevertheless, we substantially qualify the premium amount, of which the magnitude for A and AA bonds is closer to −3 bps than to −17 bps (Barclays, 2015) or −18 bps (Ehlers and Packer, 2017). Similar to HSBC (2016) and Climate Bonds Initiative (2017), we find evidence that this premium may be close to zero in several market segments, such as AAA government-related bonds or utilities. Lastly, we do not find evidence of a positive premium on USD-denominated bonds, as estimated by Karpf and Mandel (2018) (+7.8 bps).

In the final step, as a result of step 2, a green bond curve can be obtained from a conventional bond curve by applying the estimated green bond premium to the latter. This exercise is useful for investors as well as for issuers since few green bond benchmarks have been issued to date. Fig. A3 presents the reconstituted green bond curve obtained by performing specification (b) as well as the conventional bond curve for eight different issuers. The quality of the fit achieved on the entire sample is satisfactory. However, the green bond curve does not always exactly intersect with the green bond market yields for three main reasons. Firstly, the green bond premia we calculate and explain here are long-term green premia,

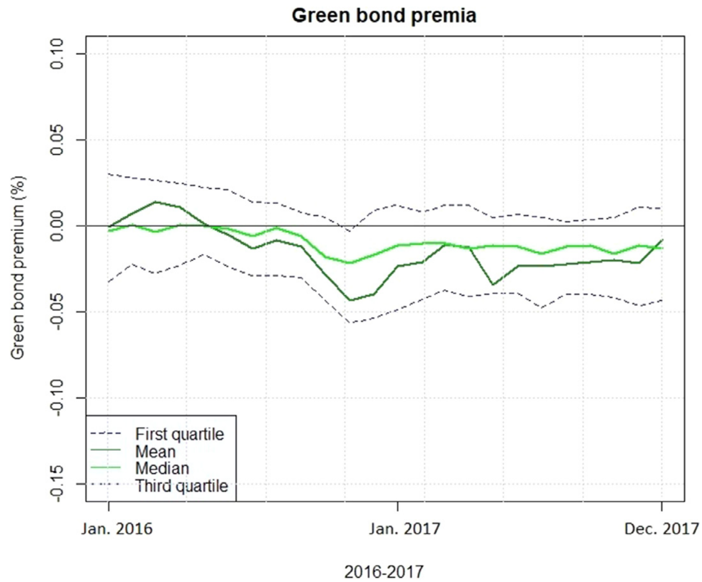

Fig. 2. Green bond premium dynamics. This figure shows the evolution over time of the mean (light green solid line), the median (dark green solid line) and the quartiles (dashed blue lines) of the green bond premium during the years 2016 and 2017 based on the step 1 regression for the entire sample of green bonds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

which reflect the average distortion since their inception. To obtain a closer fit, a short-term analysis would be more appropriate (see Section 6). Secondly, the low liquidity of several green bonds results in a yield that does not always reflect the actual yield on the reference date. Lastly, the greater the number of data available for estimating the green bond premium is, the closer the fit will be.

6. Robustness checks

In the first step of our robustness checks, we examine whether a negative premium may reflect the fact that the level of risk involved in a green bond is lower than in a conventional bond. We calculate the 10-day, 20-day and 30-day rolling annualized volatility during the period of interest in the case of both green and synthetic conventional bonds, following Eq. (3) applied to the volatility, and take the difference between the members of each pair. We then estimate a step 1 regression adding the difference in volatility as an additional independent variable (Table A3). Using a robust standard errors estimation, we find no evidence that a difference in volatility is embedded in the yield differential between green and conventional bonds. This result indicates that the green bond premium should differ from a risk premium.

Another main issue is the question as to whether or not a green bond premium remains stable with time. We add a time fixed effect in the panel regression procedure. The estimated bid-ask spread parameter is found to be significant and almost equal to the parameter estimated above. Nevertheless, the individual time effect is significant during 24% of the 1162 days considered, which means that there might not be a durable daily time effect involved in the green bond premium.

However, upon applying the same regression procedure to the whole range of data on a monthly basis from January 2016 onward, we find the green bond premium to be variable,[22] although the mean and the median premia have become and remained negative since May 2016 (Fig. 2), similar to what Karpf and Mandel (2018) reported. Moreover, interestingly, Delis et al. (2018) find a similar result on bank loans: they show that, before 2015, bank did not price climate risk and, after 2015, a 2-bps average premium is charged to fossil fuel firms compared to non-fossil fuel firms.[23] We carry out the same analysis on each rating, sector (*Government* and *Financials*) and currency (EUR and USD) subgroups and find the same pattern for most of them with different amplitude ranges (Fig. A4). It is worth noting that the robustness checks on a monthly basis are performed on rather small samples, and fewer bonds than in the main regression are therefore included. Thus, the information involved is somewhat different from that in the entire data history, which largely explains the discrepancies observed between the results.

A further potential concern is whether the green bond premium reflects a market risk premium over time. We therefore compare the daily returns of the time effects with three market indices' returns. Based on the S&P 500, the Eurostoxx 50 and the MSCI World indices, we first establish that the correlations between the index daily returns and the green bonds' time effects daily returns are low (10.9%, 7.8%, and 10.6%, respectively). In addition, to address the heteroscedasticity issue, we perform an OLS regression, with White robust standard errors,[24] to explain the daily returns of the green bond's time effects by the index daily returns (Table A4). Neither the S&P 500, the Eurostoxx 50, nor the MSCI World shows a significant effect. This analysis indicates that the time effect is not explained by a market risk premium and, hence, that the green bond premium does not reflect any market risk premium.

The quality of the matching method, as well as the interpolation or the extrapolation performed to obtain the synthetic conventional bond yield, must also be addressed. If CB1 and CB2 have significantly different levels of liquidity from that of the green bond, the first-step regression might not completely control for the residual liquidity. Furthermore, if the maturities of CB1 and CB2 differ greatly from that of the green bond, the yield of the synthetic conventional bond is liable to be over- or under-estimated.

[22] As a comparison, Longstaff et al. (2005), Favero et al. (2010), and Huang and Huang (2012) show that the liquidity premium also varies over time.

[23] More precisely, Delis et al. (2018) show that a one standard deviation increase in their measure of climate policy exposure induces a 2-bps increase of the loan rate.

[24] None of the Durbin Watson tests performed on the three specifications indicate any evidence of autocorrelation in the residuals. However, the hypothesis of homoscedasticity is rejected.

We therefore reproduce the matching method with more stringent liquidity constraints: we restrict the eligible conventional bonds to those (i) with an issue amount of less than twice the green bond's issue amount and greater than one-half of this amount and (ii) with an issue date that is, at most, two years earlier or two years later than the green bond's issue date. We also restrict the difference in maturity between CB1 and the green bond to a maximum of one year.[25] Comparing the estimated premia[26] of this sample to that of the same sample stemming from the matching constraints used in the general method, we find the descriptive statistics to be almost equal (Table A5). Moreover, after performing the step 2 regression, the estimated premia per subsample are very close for each of the two methods (Table A6). The minor difference is generally due to a poorer maturity matching with the second liquidity matching constraints. Therefore, in addition to restraining the obtained sample, requiring very stringent matching constraints can degrade the quality of the estimation.

Furthermore, we carry out a linear regression with White robust standard errors on the matched bond-day panel to explain the yield differential between GB and CB by the independent variables of specifications (a), (b), (c), (d), adding the liquidity differential control ΔBA.[27] For the sake of the comparison, we focus on the samples of 92 bonds ((a), (b) and (c)) and 84 bonds ((d)) used in the step 2 regression. The results (Table A7) confirm the necessity of controlling for the residual liquidity, although the effect is weakly significant for specifications (c) and (d). Moreover, the estimated effects are very close to that of the general method with less than 1 bp difference. However, the findings are slightly biased by overweighting the effect of bonds with the longest history. Furthermore, all of the estimated paramaters are significant, which makes it difficult to discriminate between groups on the basis of the significance of their impact on the premium. Moreover, the R^2, approximately 5%, is less satisfactory than that of the second step in our general method.

It may also be interesting to contextualize our results with those of an OLS regression with White robust standard errors of the yield of green and conventional bonds on their characteristics. We apply specifications (a) and (b) on the sample consisting of the green and the closest conventional bonds (CB1),[28] using BA (instead of ΔBA) as a control for liquidity and adding a firm fixed effect as well as a dummy variable controlling for green bonds. Likewise, we find a significant negative premium that ranges from −0.6 bp to −0.9 bp (Table A8). However, as in the previous case, this method overweights premia for which a long price history is available.

Finally, the representativeness of the green premium estimated in our sample is addressed. Fig. A5 compares the distribution of bonds in our sample with that of the global sample by rating and sector, which are the two factors that significantly influence the green premium. To assess goodness of fit, we perform a Chi-squared test on the distributions of investment-grade bonds and on three of the four most represented sectors (*Government*, *Financials*, and *Utilities*) which account for 78% of the total sample of green bonds. With P-values of 21.3% and 19.9%, respectively, we find that our green premium estimate should be reasonably representative of the overall sample for investment-grade bonds in the considered sectors. Moreover, to estimate a premium over a broader scope, we use a matching method between each green bond and one conventional bond with less restrictive criteria requiring the same issuer, currency and coupon type; we also impose a maximum maturity difference of four years and an issue amount ratio between one-quarter and four. We therefore perform a cross-sectional regression on the 179 matched pairs, accounting for 40% of the global amount of green bonds issued, controlling for all the different characteristics of the bonds. The amount of the estimated negative premium (Table A9) is found to be of a similar magnitude to that which we find with our main method. Finally, we test the robustness of the result by restricting our estimate to subsamples. By carrying out 10,000 draws with and without replacement of 40, 60 and 80 pairs among the 110 studied, we observe that more than 99% of the estimated premia are negative in the six different cases.

7. Discussion

The −2-bps average green bond yield premium (1.5% of the average yield in the sample) indicates the yield that investors are willing to give up to fund green investments rather than conventional investments with strictly equal risk. We find evidence of a low impact of investors' pro-environmental motives on bond prices. This statistically significant effect is consistent with existing theoretical works. Fama and French (2007) demonstrate that when a group of investors has a *taste* for a certain type of assets, equilibrium prices shift and the capital asset pricing model (CAPM) fails to explain asset returns. Focusing on equity, Heinkel et al. (2001) show that, by excluding polluting assets from their portfolio, *green investors* drive up the cost of capital of polluting companies. We also relate our result to the empirical finding that investors' pro-social and pro-environmental inclinations increase inflows to socially responsible investments (Hong and Kacperczyk, 2009; Riedl and Smeets, 2017; Hartzmark and Sussman, 2018), of which the psychological origin can be altruism (Brodback et al., 2018) or social pressure (DellaVigna et al., 2012). However, we show that, in contrast to the effects on the volume of financial flows, the impact on prices is very limited. In this respect, our findings suggest that the lower cost of debt for companies with good environmental performance should be predominantly related to a lower level of financial risk, through intangible asset creation[29] (Porter and van der Linde, 1995; Hart, 1995; Jones, 1995; Ambec and Lanoie, 2008; Flammer, 2015) and better risk management and mitigation (Ambec and Lanoie, 2008; Bauer and Hann, 2014), rather than investors' non-pecuniary preferences.

A negative yield differential of 2 bps for green bonds has several implications for the different types of market participants. Regarding investors, the amount of this premium should not constitute a sufficient differential likely to discourage them from investing in green bonds. Becker and Ivashina (2015) study the arbitrage of insurers between investment-grade U.S. corporate bonds with the same rating but different yields, controlling for duration and liquidity, between 2004 and 2010. In particular, they show that a positive differential of 100 bps leads to a reallocation of between 3.6% and 7.4% of insurance companies' holdings on the primary market and 0% to 2.5% on the secondary market. Given the amounts highlighted by this article in a similar framework, a -2-bps premium should therefore not constitute a disincentive to invest in green bonds. Moreover, although this premium is low, it demonstrates investors' appetite for green bond issues and thus highlights the opportunity for issuers to broaden their bondholder base by issuing green bonds, as suggested by I4CE (2016). This premium is

[25] Requiring the same restriction on CB2 leads to a total sample of only 30 matched pairs of bonds and, thus, to very small subsamples.

[26] The independent variable in step 1, ΔBA, is no longer significant with the second matching method, demonstrating that there is almost no more residual liquidity to be controlled.

[27] It is worth noting that, as in our two-step regression, the better the matching, the more accurate the estimations.

[28] The same method could be applied to non-matched bonds, but the results would be much less accurate and would not be comparable with those of the main method presented in this paper.

[29] Intangible assets may refer to an improvement in the company's reputation, the attraction of new customers or a greater loyalty of employees towards the company.

also consistent with the results of Flammer (2018), who finds that green bond issuances induce an increase in ownership by long-term and green investors. Finally, from the supervisory authority perspective, this result addresses the concern about the appearance of a bubble on green assets raised by the Dutch Central Bank (De Nederlandsche Bank, 2017): while the amount of this premium indicates investors' preference for green bonds, it does not yet reveal any substantial pricing discrepancy between green and conventional bonds.

The opportunity to increase the issuance of green bonds, which still accounted for 1.3% of the outstanding global debt in 2017,[30] is not only supported by the results of this paper but also consistent with political ambitions and the recommendations of financial players. Policymakers can play a crucial role by providing green project developers and investors with a clearer legal framework to unlock the full potential of the green bond market. Indeed, as recommended by the EU High-Level Group on Sustainable Finance (EU HLEG, 2018), the European Commission set a roadmap on March 8, 2018, to establish a common taxonomy (*EU Classification System*) for sustainable finance and to create EU labels for green financial products based on this classification (European Commission, 2018). These actions will notably help establish a precisely defined framework for green bond requirements and should streamline the approval process to increase the flow of low-carbon projects.[31]

8. Conclusion

In this paper, we use green bonds as an instrument to identify the effect of non-pecuniary motives, specifically pro-environmental preferences, on bond market prices. We analyze the yield of green bonds compared to that of equivalent synthetic non-green bonds through a matching method for bonds issued from July 2013 to December 2017. We identify the effect of pro-environmental preferences through a *green bond premium*, which is defined as the yield differential between a green bond and its counterfactual conventional bond after controlling for their difference in liquidity. We evidence a significant, albeit low, premium related to investors' pro-environmental preferences in the bond market. This result highlights the opportunity for issuers to benefit from an expansion of their bondholder base through this asset class, especially for low-rated and financial bonds. However, at this stage, the premium is still low enough not to demonstrate any substantial valuation discrepancy between green and conventional bonds or to dissuade investors from supporting the development of the green bond market.

The main limitation of this study arises from the quality of the data. Since bonds–and *a fortiori* corporate bonds–are not frequently traded, a bond yield does not accurately reflect the fair value of the bond in some cases. Further research along these lines could focus on pursuing the following two main objectives. An empirical study could be performed to assess whether the use of proceeds has a differentiating impact on the premium. This study could also be extended to social impact bonds, once this market is sufficiently mature, to analyze the impact of pro-social preferences on bond prices.

Appendix. Tables

Table A1
Average issue amount broken down per type of bond and currency. This table gives the average amount of green bonds, CB1 and CB2 issued in each currency.

	Average issue amount (bn USD)		
	Green bonds	Conventional bonds 1	Conventional bonds 2
AUD	0.45	0.63	0.64
CAD	0.40	1.11	0.95
CHF	0.33	0.29	0.35
CNY	0.23	0.15	0.08
EUR	1.05	1.95	1.98
GBP	1.89	6.84	2.47
INR	0.08	0.30	0.22
JPY	0.09	0.15	0.17
RUB	0.01	0.10	0.01
SEK	0.11	0.13	0.13
TRY	0.07	0.03	0.10
USD	0.65	1.50	1.38
Average	0.65	1.34	1.24
Median	0.28	0.29	0.28

Table A2
Results of the step 2 regression on the entire sample. This table gives the result of the step 2 regression in which the green bond premium is explained by the characteristics of the bonds through specification (a) on the entire sample of 110 bonds.

	Dependent variable: $\widehat{p}_i$
	Linear regression with White robust standard errors
Constant	−0.005
	(0.011)
Rating AA	-0.022**
	(0.010)
Rating A	−0.023*
	(0.014)
Rating BBB	−0.040
	(0.044)
Rating BB	−0.194***
	(0.010)
Non-rated	−0.011
	(0.018)
Sector Basic Materials	−0.011
	(0.018)
Sector Consumer, Non-cyclical	0.031
	(0.046)
Sector Financial	−0.007
	(0.012)
Sector Industrial	0.047
	(0.046)
Sector Utilities	0.037
	(0.034)
Currency AUD	−0.007
	(0.014)
Currency CAD	−0.005
	(0.013)
Currency CHF	0.020
	(0.015)
Currency CNY	0.059***
	(0.012)
Currency EUR	0.003
	(0.011)
Currency GBP	0.007
	(0.020)
Currency INR	0.060***
	(0.011)
Currency JPY	0.062**
	(0.024)
Currency RUB	−0.376***
	(0.011)
Currency SEK	0.011
	(0.011)
Currency TRY	0.084***
	(0.011)
Observations	110
R^2	0.606
Adjusted R^2	0.513
Residual Std. Error	0.040 (df = 88)
F Statistic	6.459*** (df = 21; 88)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

[30] According to the Bank for International Settlements, the total outstanding debt worldwide amounted to USD 23,580 billion in the third quarter of 2017: https://www.bis.org/statistics/c1.pdf.

[31] In 2016, green bonds accounted for only 17% of the USD 694 billion climate-aligned bonds universe (Climate Bonds Initiative, 2016) that gathers numerous potential candidates for a green bond label.

Table A3
Results of the step 1 regression with a control of the difference in volatility. This table gives the results of the step 1 regression to which the difference in volatility between green and conventional bonds is added as an independent variable: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta BA_{i,t} + \Delta Vol_{i,t} + \epsilon_{i,t}$. Newey-West and Beck-Katz robust standard error tests are performed.

	Dependent variable: $\Delta\tilde{y}_{i,t}$					
	Newey–West	Beck–Katz	Newey–West	Beck–Katz	Newey–West	Beck–Katz
ΔBA	-11.778^{***}	-11.778^{***}	-12.316^{***}	-12.316^{***}	-12.484^{***}	-12.484^{***}
	(3.178)	(3.861)	(3.330)	(3.989)	(3.459)	(4.129)
Δ 10-day volatility	−0.020	−0.020				
	(0.040)	(0.049)				
Δ 20-day volatility			0.037	0.037		
			(0.055)	(0.086)		
Δ 30-day volatility					0.017	0.017
					(0.060)	(0.119)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A4
Green premium and market returns. This table shows the regression of the daily returns of the time effects in the step 1 regression on the daily returns of several market indices.

	Dependent variable: Time effects' returns		
	White robust std. err. estimation		
Constant	-0.818^{**}	-0.764^{**}	-0.802^{**}
	(0.416)	(0.380)	(0.402)
S&P 500 returns	184.449		
	(133.206)		
Eurostoxx 50 returns		85.116	
		(60.130)	
MSCI World returns			203.006
			(135.363)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A5
Descriptive statistics of more stringent matching criteria. This table gives the descriptive statistics of the estimated green bond premia through a step 1 regression on two different samples: a) the sample stemming from the matching criteria #2 and b) the sample stemming from the matching criteria #1 restricted to bonds in sample a). Matching criteria #1 require the conventional bonds to have (i) a maturity that is neither two years shorter nor two years longer than the green bond's maturity, (ii) an issue amount of less than four times the green bond's issue amount and greater than one-quarter of this amount, and (iii) an issue date that is at most six years earlier or six years later than the green bond's issue date. Matching criteria #2 require the conventional bonds to have (i) a maturity that is neither one (resp. two) year(s) lower nor one (resp. two) year(s) greater than the green bond's maturity for CB1 (resp. CB2), (ii) an issue amount of less than twice the green bond's issue amount and greater than one-half of this amount, and (iii) an issue date that is, at most, two years earlier or two years later than the green bond's issue date.

	Green bond premia	
	Matching 2	Matching 1 on M2's sample
Min.	−0.130	−0.127
1st Quartile	−0.034	−0.039
Mean	−0.020	−0.018
Median	−0.012	−0.011
1st Quartile	0.003	0.001
Max.	0.079	0.079

Table A6

Estimated premia using more stringent matching criteria, broken down by rating and sector. This table gives the estimated average EUR and USD premia through a step 2 (b) regression using bonds stemming from matching criteria #1 and matching criteria #2, both restricted to the same largest common sample. The premia are broken down by ratings and sector. Matching criteria #1 require the conventional bonds to have (i) a maturity that is neither two years shorter nor two years longer than the green bond's maturity, (ii) an issue amount of less than four times the green bond's issue amount and greater than one-quarter of this amount, and (iii) an issue date that is at most six years earlier or six years later than the green bond's issue date. Matching criteria #2 require the conventional bonds to have (i) a maturity that is neither one (resp. two) year(s) shorter nor one (resp. two) year(s) longer than the green bond's maturity for CB1 (resp. CB2), (ii) an issue amount of less than twice the green bond's issue amount and greater than one-half of this amount, and (iii) an issue date that is at most two years earlier or two years later than the green bond's issue date.

Matching criteria		EUR		USD	
		Govt	Financials	Govt	Financials
1	AAA	−0.00	−0.02	−0.02	−0.04
2		−0.02	−0.03	−0.03	−0.04
1	AA		−0.02		−0.04
2			−0.01		−0.01
1	A		−0.02		−0.04
2			−0.03		−0.04
1	BBB		−0.02		−0.04
2			−0.03		−0.04

Table A7

Results of a step 2 regression performed on the difference in the yield while controlling for the difference in liquidity. This table gives the results of step 2 regressions performed on the bond-day sample in which we explain the yield differential by a proxy of the difference in liquidity ΔBA and the bonds' characteristics of specifications (a),(b), (c), and (d). The yield differential and ΔBA are expressed as percentages. The rating is a qualitative variable, of which the four modalities are AAA (reference modality), AA, A and BBB. Maturity is the maturity of the bond expressed in years on December 31, 2017. The issue amount is the amount of green bonds issued expressed in USD billions. Sector is a qualitative variable, of which the three modalities are Government (reference modality), Financials and Utilities. We also consider Rating $\times$ Sector cross effects. Currency is a qualitative variable, of which the four modalities are USD (reference modality), AUD, EUR, and SEK.

	Dependent variable: $\Delta\tilde{y}_{i,t}$			
	Linear regressions with White robust standard errors			
	(a)	(b)	(c)	(d)
Constant	0.001	-0.006^{***}	-0.002^{***}	-0.009^{***}
	(0.001)	(0.001)	(0.001)	(0.001)
ΔBA	-1.378^{***}	-1.399^{***}	-0.939^{*}	0.578
	(0.533)	(0.521)	(0.500)	(0.460)
Rating AA	-0.014^{***}	-0.019^{***}	-0.021^{***}	
	(0.001)	(0.001)	(0.001)	
Rating A	-0.028^{***}	-0.030^{***}	-0.031^{***}	
	(0.001)	(0.001)	(0.001)	
Rating BBB	-0.026^{***}	-0.035^{***}	-0.038^{***}	
	(0.003)	(0.003)	(0.003)	
Non-rated	-0.006^{***}	-0.009^{***}	-0.002^{**}	
	(0.001)	(0.001)	(0.001)	
Sector Financial	-0.010^{***}	-0.009^{***}	-0.006^{***}	
	(0.001)	(0.001)	(0.001)	
Sector Utilities	0.027^{***}	0.034^{***}	0.041^{***}	
	(0.002)	(0.002)	(0.002)	
AA $\times$ Government				-0.014^{***}
				(0.002)
AAA $\times$ Financial				0.006^{***}
				(0.001)
AA $\times$ Financial				-0.019^{***}
				(0.001)
A $\times$ Financial				-0.033^{***}
				(0.001)
NR $\times$ Financial				-0.002^{**}
				(0.001)
Currency AUD	0.003^{***}	−0.0003		
	(0.001)	(0.001)		
Currency EUR	0.c12***	0.009^{***}		
	(0.001)	(0.001)		
Currency SEK	0.028^{***}	0.014^{***}		
	(0.002)	(0.001)		
Maturity	-0.002^{***}			
	(0.0002)			
log(Issue Amount) (bn USD)	0.007^{***}			
	(0.001)			
Observations	33,127	33,127	33,127	28,682
R^2	0.059	0.053	0.049	0.046
Adjusted R^2	0.059	0.052	0.049	0.045
Residual Std. Error	0.071 (df = 33114)	0.071 (df = 33116)	0.071 (df = 33119)	0.071 (df = 28675)
F Statistic	173.178^{***} (df = 12; 33114)	183.831^{***} (df = 10; 33116)	243.608^{***} (df = 7; 33119)	228.418^{***} (df = 6; 28675)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A8
Results of an OLS regression of the yields on the characteristics of green and conventional bonds. This table provides the results of an OLS regression with White standard errors performed on the yields of the green and the closest conventional bonds (CB1). Following specifications (a) and (b), the yields are explained by the characteristics of the bonds (rating, sector, currency, maturity) and a control for liquidity (bid-ask spread, BA), to which a dummy variable for green bonds and a firm fixed effect are added. The issue amount is not included in this regression since the bid-ask spread is used to control for bonds' liquidity.

	Dependent variable: Bonds' yields	
	(a)	(b)
Constant	1.633***	1.748***
	(0.010)	(0.015)
Green	−0.006**	−0.009***
	(0.002)	(0.003)
BA	80.880***	134.779***
	(4.009)	(5.169)
Maturity	0.082***	
	(0.001)	
Rating control	Yes	Yes
Sector control	Yes	Yes
Currency control	Yes	Yes
Firm control	Yes	Yes
Observations	66,254	66,254
R^2	0.905	0.890
Adjusted R^2	0.905	0.890
Residual Std. Error	0.312 (df = 66198)	0.336 (df = 66199)
F Statistic	11,515.150*** (df = 55; 66198)	9,928.532*** (df = 54; 66199)

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table A9
Results of an OLS regression of the yields on the characteristics of green and conventional bonds matched with less stringent criteria. This table provides the results of an OLS regression with White standard errors performed on the yields of the green and the matched conventional bonds with less stringent criteria than the main matching method. We require that both bonds have the same issuer, currency, coupon type, a maximum maturity difference of four years and an issue amount ratio of between one-quarter and four. The yields are explained by the characteristics of the bonds (rating, sector, currency, maturity, collateral, coupon type, bullet/callable structure) and the price percentage bid-ask spread as control for liquidity, to which a dummy variable for green bonds is added. The 179 bond pairs are studied over the same time period as the main regression: from July 18, 2013 to December 31, 2017.

	Dependent variable: Bonds' yields
Constant	3.284***
	(0.049)
Green	−0.042***
	(0.003)
Maturity	0.099***
	(0.001)
Bid-Ask	21.952***
	(0.560)
Rating control	OK
Sector control	OK
Currency control	OK
Collateral control	OK
Coupon type control	OK
Bullet/Callable control	OK
Observations	138,272
R^2	0.901
Adjusted R^2	0.901
Residual Std. Error	0.649 (df = 138226)
F Statistic	27,975.340*** (df = 45; 138226)

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

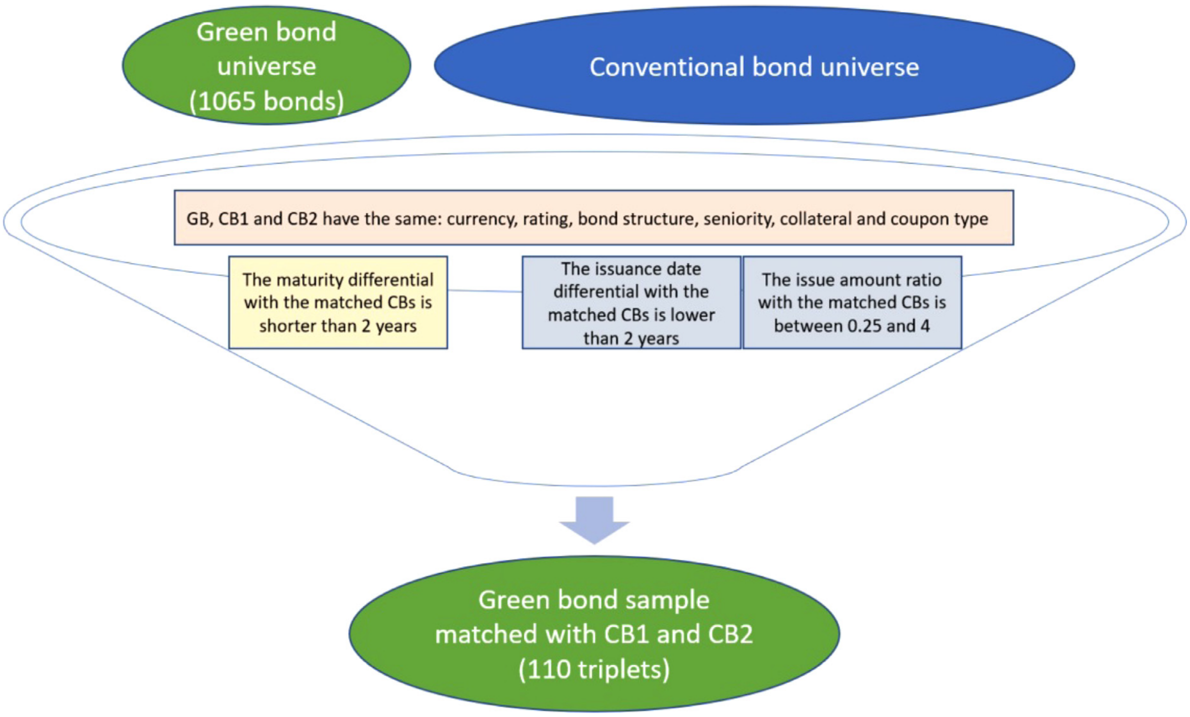

Fig. A1. Matching process. This figure illustrates the matching process. We match each green bond (GB) of the universe on December 31, 2017, with two conventional bonds (CB1 and CB2). Green and conventional bonds are required to have the same currency, rating, bond structure, seniority, collateral and coupon type. Moreover, the maturity of the conventional bond is neither two years shorter nor two years longer than that of the green bond. Also, we select the conventional bonds (i) with an issue amount of less than four times the green bond's issue amount and greater than one-quarter of this amount. We therefore collect 110 triplets of (GB, CB1, CB2).

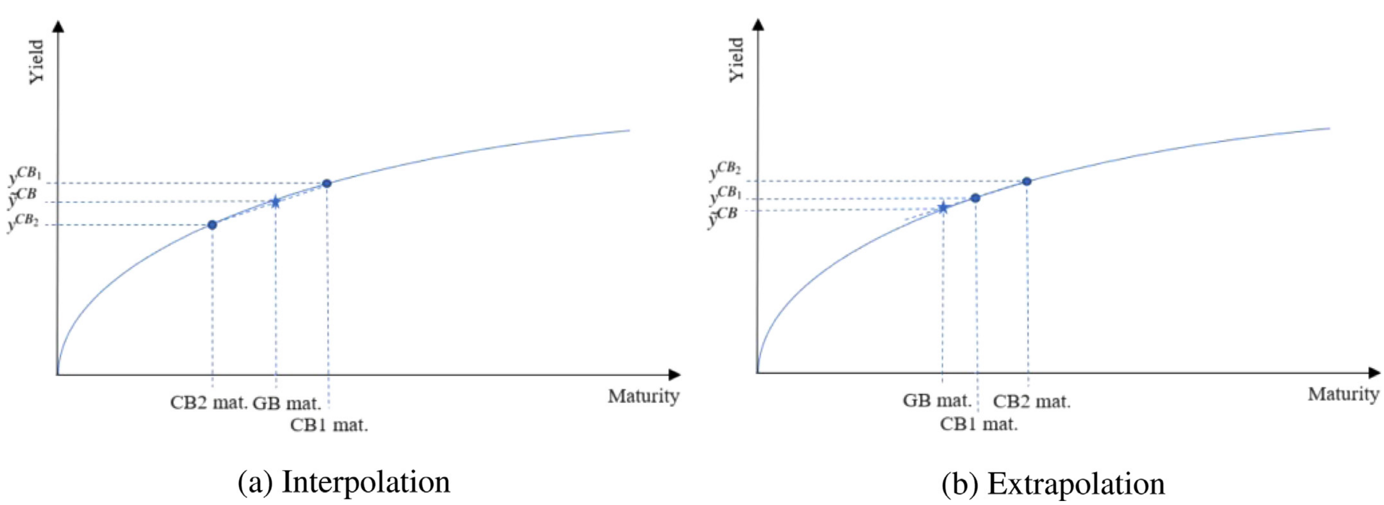

Fig. A2. Interpolation and extrapolation of the synthetic conventional bond yield. This figure shows how we calculate the yield of the synthetic conventional bond through (a) a linear interpolation or (b) a linear extrapolation of the yields of CB1 and CB2 at the maturity date of the green bond.

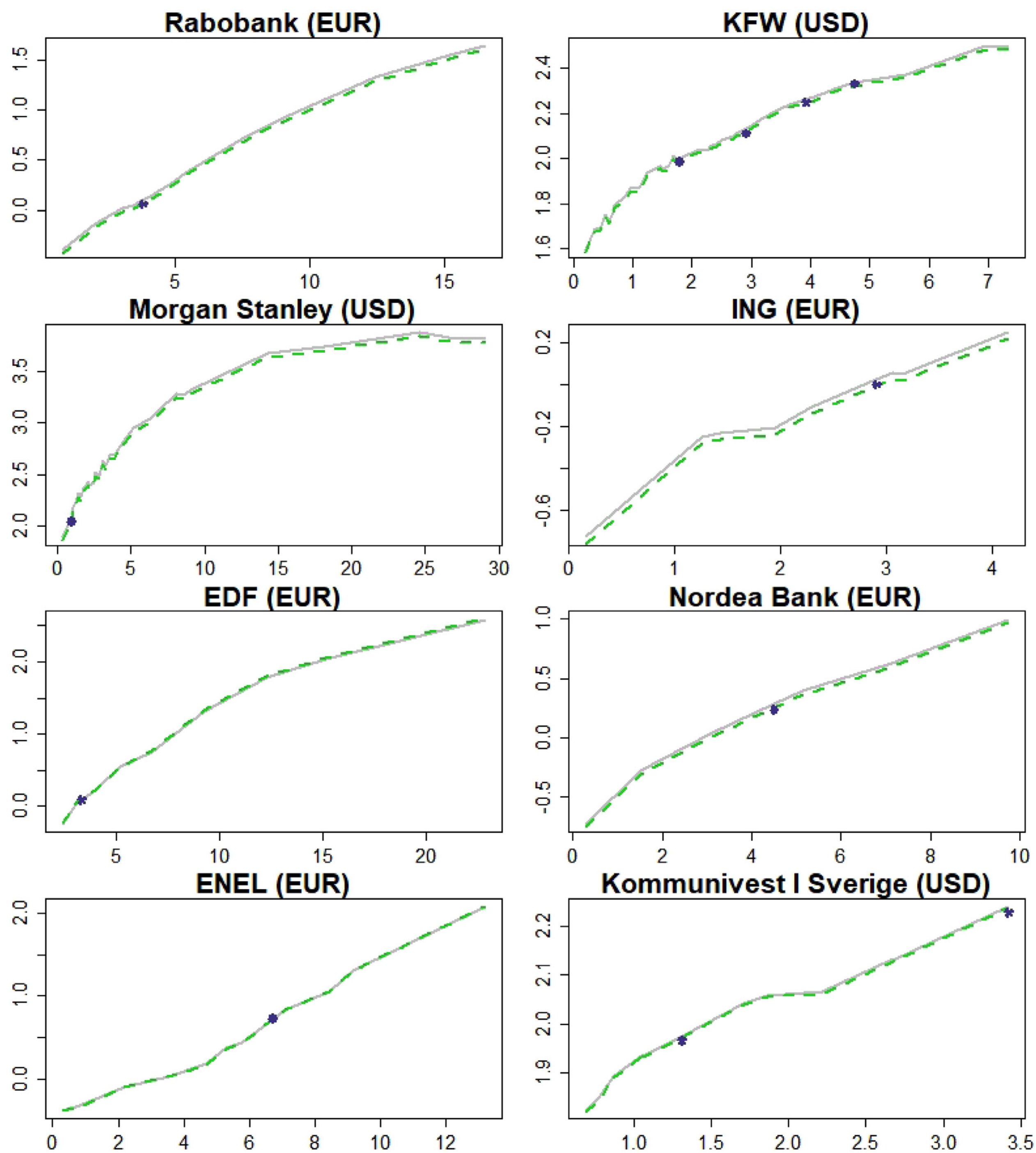

Fig. A3. The green bond yield curves. This figure shows eight green bond curves (green dashed lines) reconstituted from conventional bond curves (grey solid lines) based on the parameters estimated in step 2 of regressions (b) performed on EUR and USD bonds. The market yields of the green bonds are also shown (blue stars). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

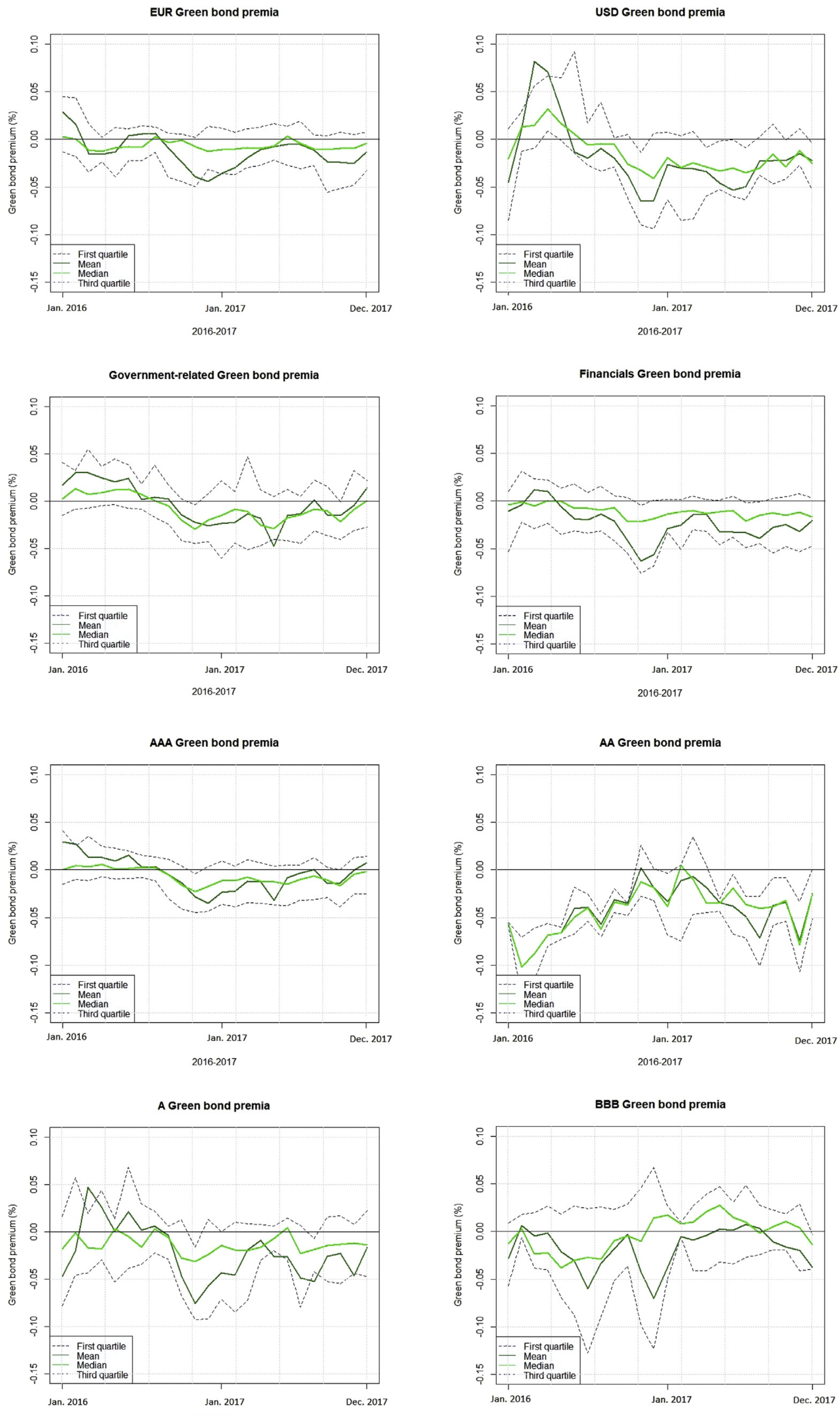

Fig. A4. Green bond premium dynamics per group. These figures show the evolution over time of the mean (light green solid line), the median (dark green solid line) and the quartiles (dashed blue lines) of the green bond premia brokend down by groups during the years 2016 and 2017 based on the step 1 regression for the entire sample of green bonds. The groups are as follows: (i) EUR, (ii) USD, (iii) Government-related, (iv) Financials, (v) AAA, (vi) AA, (vii) A, and (viii) BBB green bonds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

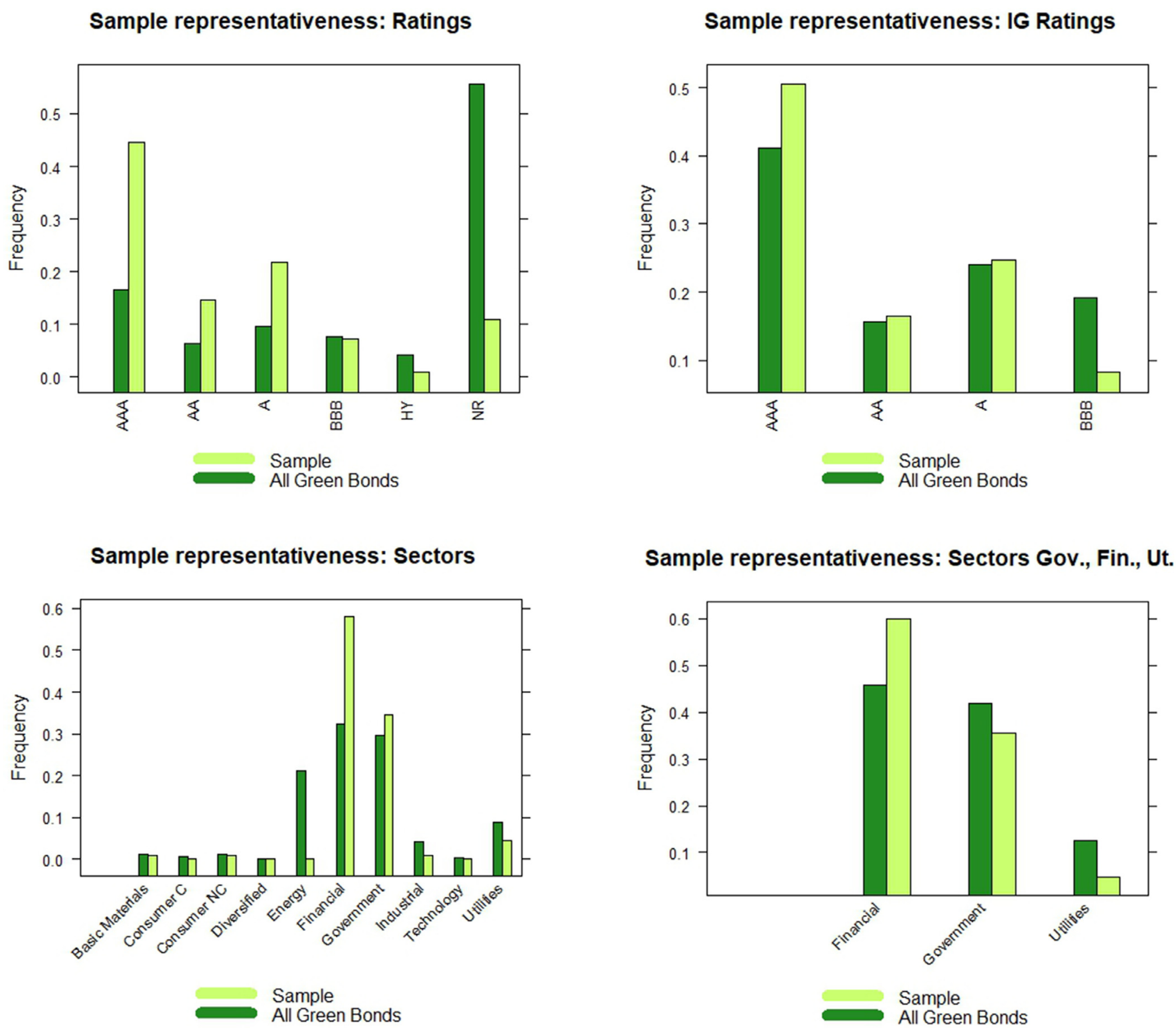

Fig. A5. Analysis of the representativeness of the matched sample. This figure shows the distribution, by sector and rating, of green bonds in the matched sample (110 bonds) compared to the distribution of those in the global universe (1065 bonds). The right-hand figures correspond to the left-hand figures, and the comparison is focused on investment-grade bonds for the top figure and the Financial, Government, and Utilities sectors for the bottom figure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jbankfin.2018.10.012.

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