# The Green Bond Premium

Olivier David Zerbib* †

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*"Act so that the effects of your action are compatible with the permanence of genuine human life."*
Hans Jonas, 1984. The Imperative of Responsibility. The University of Chicago Press.

**Abstract**

Using a matching method, we estimate and analyze the green bond premium, defined as the difference in yield between a green bond and an equivalent synthetic conventional bond. For the sake of accuracy, we focus our analysis on 135 Investment Grade senior bullet fixed-rate green bonds issued worldwide. The average green bond premium is found to be significantly negative from the green bonds' issuance date to December 30, 2016, especially in several market segments such as below-AAA EUR and USD bonds where the issued amount is greater than USD 100 million (-4 bps and -9 bps, respectively). We then explain this premium by the characteristics of the bonds to reconstitute a green yield curve. We conclude that regulatory and fiscal measures could help to continue feeding the pipeline and create incentive for increasing the volume of green bond issuances.

**JEL Classification**: C23; G12; G14; G20; Q56
**Keywords**: Green bonds; Low-carbon finance; Sustainable finance; Asset management; Market microstructure; Liquidity

*Department of Finance, Tilburg School of Economics and Management, and CentER, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands. Université de Lyon, Université Lyon 1, Institut de Sciences Financière et d'Assurances, 50 avenue Tony Garnier, F-69007 Lyon, France. I Care & Consult, 28 rue du 4 Septembre, 75002 Paris, France. Mail: olivier-david.zerbib@etu.univ-lyon1.fr.

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# 1 Introduction

One of the main innovations presented in the Conference of Parties (COP) 21 agreement was the statement that restricting the temperature increase to 1.5 degrees Celsius involves "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development". To set the world on an appropriate path for achieving this 1.5-degree goal, the need for cumulative investment in energy supply and energy efficiency will predictably reach USD 93 trillion by 2030 according to the *New Climate Economy* report chaired by Nicholas Stern and Felipe Calderon. This figure can be compared with the total assets held by the OECD institutional investors[1], which amounted to USD 92.6 trillion in 2013 (OECD (2015)). In the OECD member countries, the public sector accounts today for two thirds of the investments in sustainable energy infrastructures, while the private sector already provides the remaining third (OECD (2015)). Private investors therefore have the resources required to drive and amplify the environmental transition by supplementing public funding and complementing the current regulations.

While banks are less prone to expand their balance sheets to finance the additional requirements of the renewable energy sector as the Basel III framework and the Capital Requirements Directive (CRD IV) have prompted them to reduce their investments in illiquid asset classes and long-term instruments, institutional investors have been taking an interest in the possibility of including sustainable environmental investments in their assets, especially as many of them regard climate change as a threat to long-term economic growth. Many initiatives have therefore been launched to *decarbonize* portfolios and redirect assets towards green investments. The Portfolio Decarbonization Coalition rallied 25 institutional investors who committed themselves to decarbonizing up to USD 600 billion out of the USD 3.2 trillion assets currently under management. In addition, by signing the Montreal Carbon Pledge, more than 120 investors with assets under management worth more than USD 10 trillion have agreed to support the development of the green bond market and to measure and publish the carbon footprint of their investments on an annual basis.

[1] Institutional investors include pension funds, insurance companies and sovereign wealth funds. If we take these investors to include banks, they hold more than 80% of the institutional assets under management in middle-income countries (McKinsey (2016)).

These trends have also been supported and strengthened by national regulations in both industrialized and emerging countries (see UNEP (2016a) for an extensive review): China has drawn up a system of directives to lay the foundations for a green financial system (People's Bank of China (2016)), France has passed a law on the energy transition, which requires institutional investors to declare how they are contributing to reducing greenhouse gas emissions (see article 173, French Treasury (2015)), the Bank of England (Bank of England (2015)) and the Securities and Exchange Board of India have both issued new requirements to promote the development of the green bond market (UNEP (2016b)).

The development of the expanding green bond market has been an essential lever which has encouraged institutional investors to efficiently diversify their assets by moving towards sustainable investment projects. The Green Bond Principles[2] are "voluntary process guidelines that recommend transparency and disclosure, and promote integrity in the development of the Green Bond market". They provide issuers with guidance and ensure that reliable information is available to potential investors about the environmental impact. Thanks to the development of this standard, green bonds have become a standardized asset class providing predictable cash flows and sufficient amounts of collateral, in keeping with institutional investors' traditional asset allocation[3].
The labelled green bond market reached USD 115 billion outstanding in March 2016 (Climate Bonds Initiative (2016)). The volume of issuances is almost doubling year after year: USD 42 billion were issued in 2015, USD 81 billion in 2016 and this figure is expected to reach USD 150 billion in 2017 (Climate Bonds Initiative (2017)). Although the public development banks are still the main issuers, the share of corporate and financial green bonds is constantly on the increase: 45 different corporates and banks emitted green bonds in March 2016, as against 30 and 10 in 2013 and 2012, respectively. The vast majority (82%) of the green bonds issued are investment grade

[2]The 2016 voluntary process guidelines for issuing green bonds are summarized in: http://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/GBP-2016-Final-16-June-2016.pdf.

[3]Bonds correspond to the main asset class in which pension funds and insurance companies invest: they account for 53% and 64% of their assets under management, respectively (OECD (2015)). The total volume of debt issued in 2013 amounted to around USD 100 trillion (Bank for International Settlements (2014)).

bonds; the energy sector is the main sector involved (43%) and the major maturity range is five to ten years. The main currencies involved are the USD and the EUR, each of which accounts for more than USD 40 billion in issued bonds.

The funding cost, which is a crucial variable for financing green projects as well as for the investors, involves some strategic issues. A low funding cost is a key to achieving sustainable infrastructure development: as the cost of sustainable energy infrastructures is decreasing, the cost of financing becomes the major factor on which the long term cost of electricity depends. However, although some institutional investors compete for acquiring green debt, the prospects of a lower yield may discourage all the other investors who are not obliged to invest partly in green financial instruments. In OECD member countries' pension funds, asset allocation to green investments is still below 1% (Della Croce et al. (2011)).

This paper therefore aims to provide answers to the following questions: Is there a lower yield for investors financing the environmental transition? Are project holders able to issue green bonds at a lower yield than that of conventional bonds? What are the consequences in terms of market microstructure?

In other words, the main issue it is proposed to address here is whether green bonds are specifically associated with a negative premium. Putting it differently, is a green bond yield lower than that of a completely equivalent non-green bond (which will be called *a conventional bond* from now on)?

To answer this question, a matching method is first used to calculate the yield of an equivalent synthetic conventional bond for each live green bond issued before December 30, 2016. Since the only parameter which cannot be modelled is the bond liquidity, we control the difference in liquidity between each green bond and its equivalent synthetic conventional bond in order to extract a green premium via a fixed effect panel regression. The green premium is therefore the unobserved specific effect of the regression of the difference in yields between the two bonds on the difference in liquidity. The advantage of this approach is that there is no need to express the green bond premium in terms of fundamental variables which would inevitably bias the estimation. In the second step, we explain this green premium by the specific characteristics of the bond in order to identify the factors affecting the costliness of green bonds. Lastly, the reasons for the distortion of the market microstructure observed are discussed.

To our knowledge, this is the first study focusing on the specific cost of green bonds. The most original feature of this study is that we are working on newly emerging data in an initial exhaustive green bond database without adopting any prior assumptions in our analysis, using the ask yield to focus on the investors' green bond demand and the issuers' green bond supply.

The main contributions of this study are threefold. First, we present a method for analyzing the costliness of bonds with specific proceeds, whether they are green bonds or social impact bonds. This is all the more worthwhile as bonds need to be priced even when only a few benchmarks have been issued. Secondly, in line with the stakeholder theory, we show that there is a significantly negative premium on green bond yields, which we quantify here and explain on the basis of the characteristics of the bonds. For example, focusing on Investment Grade bonds with an issued amount greater than USD 100 million, the average premium is significantly negative in various market segments such as EUR bonds with a rating lower than AAA (-4 basis points) and USD bonds with a rating lower than AAA (-9 basis points). Lastly, we point out that, although this situation is conducive to increasing the green bond issuance with a primary yield lower than the conventional benchmark, it highlights the lack of green debt issuance despite the strong buying demand and calls for regulatory and fiscal measures to continue feeding the pipeline and create incentive for increasing the volume of green bond issuances.

This paper is organized as follows. In the second section, the literature on the topics 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 to which our findings point are summarized in section eight.

# 2 Literature review

This study builds on three strands in the literature: (i) studies assessing the effects of firms' environmental performances on their bond yields, (ii) studies based on the matching method, in which a model-free approach is used to determine the intrinsic value of specialized financial instruments, and (iii) studies on liquidity proxies.

## *2.1 Effects of environmental performances on bond yields*

Few academic studies have focused so far on the effects of CSR performances, especially environmental performances, on corporate bond yields. Nor have any unequivocal conclusions yet been reached on this topic. Menz (2010) focuses on European corporate bond market and observes that socially responsible firms suffer from greater credit spread than non-socially responsible companies, although this finding is only slightly significant. Stellner et al. (2015) obtain fairly weak evidence that good CSP systematically reduces credit risks. Conversely, Bauer and Hann (2014), based on information provided by a large cross-industrial sample of US public corporations, have established that environmental strengths are associated with a lower cost of debt. Broadening the scope to CSR issues, Oikonomou et al. (2014) show that good CSR performances are rewarded via a lower yield and CSR irresponsibility is positively correlated with financial risk on US corporate debt. Ge and Liu (2015) focus on the effects of CSP disclosure on the spreads of new corporate bonds issued in the US primary market and establish that firms reporting favorable CSPs enjoy lower bond spreads.

However, no academic studies on the cost of the "greenness" of bonds have ever been published so far. The studies mentioned above are not based on the type of financial instrument but on the characteristics of the company involved. Analyzing the green bond market therefore provides a practical means of dealing with this topic. The OECD (2017) report states that the financial characteristics of green bonds and conventional bonds produced by the same issuer are identical on the issue date ("flat pricing") because investors are not willing to pay a premium to go for green investments. I4CE (2016) argues that although increasing socially responsible investors' demand for green bonds is liable to lower the yield, there still is "no clear evidence" that green bonds reduce the cost of capital for their issuers. However, three bank reports (Barclays (2015), Bloomberg (2017) and HSBC (2016)) tackle the issue of a green bond premium on the secondary market. They focus on a small number of bonds[4], do not control for the difference in liquidity and do not use any analytical techniques to compare green bond yields with conventional bond yields - apart from Barclays (2015) that consider an OLS regression of the credit spread on some market risk factors. While the first two studies point to the existence of a strongly negative green bond premium (-17 bps and -25 bps, respectively), HSBC (2016) claims that the cases of negative and positive premia found do not show the existence of a systemically negative premium. Lastly, focusing specifically on callable US municipal bonds, Karpf and Mandel (2017) analyze the green bond yields in comparison with non-green bond yields and show the existence of a 7.8 bps-positive green premium in this market segment. The issues of the existence and *a fortiori* the determinants of a green bond premium are therefore still open-ended questions, which it is proposed to address in this study focusing on a global database.

## 2.2 *The matching method*

The empirical method mostly used to analyze bond spreads and yields consists in performing an appropriate regression on a suitable specification. This requires determining the financial and extra-financial independent variables likely to explain the intrinsic value of the bond yield as exhaustively as possible. This approach has at least three main drawbacks, however. First, there is no consensus as to how exactly a bond yield should be broken down, *a fortiori* when the aim is

[4]The scope is the Global Credit universe in August 2015, 12 supranational bonds and 30 bonds, respectively.

to identify and explain the premium inherent to green bonds. In addition, when the specification includes too many independent variables, various issues arise such as the increased risk of colinearity, the potential lack of data and the problem of robustness.

The matching method, which is also known as a model-free approach or a direct approach, is a useful technique for analyzing the specificity of a financial instrument. It consists in matching a pair of instruments having the same characteristics except for the one characteristic in which we are interested from the point of view of its effects. This method has been used to assess the additional return of ethical funds in comparison with identical conventional funds or indices. Upon analyzing 30 pairs of European ethical and non-ethical funds, Kreander et al. (2005) conclude that there is no difference in performance, whereas Renneboog et al. (2008) report that 440 global socially responsible investment funds underperform in comparison with their non-ethical benchmarks. Bauer et al. (2005) use another version of the matching method on 103 German, UK and US ethical funds and find little evidence of significant differences in the risk-adjusted returns during the 1990-2011 period. This method has also been used specifically on bonds, to assess the yield cost of liquidity. Longstaff and Schwartz (1995) determine the cost of liquidity by comparing CDS and corporate bonds, while Amihud and Mendelson (1991), Kamara (1994) and Helwege et al. (2014) assess the cost of liquidity by matching and comparing pairs of bonds issued by the same firm with the same characteristics except for their degree of liquidity.

## *2.3 The cost of liquidity and liquidity proxies*

It is widely agreed that bond credit spreads incorporate a liquidity premium which is all the higher as the credit rating is low (Chen et al. (2007), Beber et al. (2009), Bao et al. (2011), Dick-Nielsen et al. (2012), de Jong and Driessen (2012)).

A vast body of literature on liquidity-control metrics, which we break up into three categories, has been published during the last three decades.

The first class of illiquidity measures involves the use of indirect proxies based on the bond's characteristics such as its age, the amount issued, the coupon and the bond covenants. In particular, Bao et al. (2011) and Houweling et al. (2005) not unexpectedly establish that the amount issued and the age of the bond are suitable proxies reflecting the degree of illiquidity.

In the second class of illiquidity measures, the proxies are based on aspects of trading activity such as the bid-ask spread, volume, number of trades and number of dealers. The bid-ask spread is defined as the spread between the bid price and the ask price at the end of each trading day (see Beber et al. (2009), Dick-Nielsen et al. (2012), Chen et al. (2007)). The market-depth indicators include the average depth quoted (Beber et al. (2009), Dick-Nielsen et al. (2012)), defined as the average depth posted at the best bid and best ask prices, the limit-order book depth (Beber et al. (2009)), which is the average sum of the three best bids' depth and the three best asks' depth, and the turnover measure, defined as the total trading volume divided by the outstanding amount (e.g. see Dick-Nielsen et al. (2012)).

The third class of illiquidity measures consists of estimators of market impact, transaction costs or turnover. The *Kyle lambda* (Kyle (1985)), the *Amihud measure* (Amihud (2002)) and the *Range measure* (Han and Zhou (2016)) indicate the daily price, the daily return response and the daily price variability per unit of trading volume, respectively. Another type of bond liquidity proxy is a function of the autocovariance of the daily return (Roll (1984)) or price move (Bao et al. (2011)) and the one-day lagged daily return or price move: the greater this measure, the more illiquid the bond will tend to be. The price dispersion measure is based on the dispersion of market prices around its consensus valuation by market participants (see Jankowitsch et al. (2011)). Lastly, the zero-trading-days measure is a proxy for bond liquidity, since the greater the percentage of zero-trading days during a given period, the more illiquid the bond will be (see Chen et al. (2007) and Dick-Nielsen et al. (2012)).

# 3 Data description

We set up this database in order to evaluate the yield spread between a green bond and an equivalent synthetic conventional bond. For this purpose, we take matched pairs of bonds consisting of a green bond and a conventional bond with identical characteristics except for its 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: the impact of this parameter on the bond yield is what we want to assess. The difference between the green bond yield and the equivalent synthetic conventional bond yield is therefore exactly the cumulative effect of the liquidity differential and a premium that we call the "green bond premium".

We examine the entire sample of 681 green bonds complying with the Green Bond Principles on December 30, 2016. This set includes bonds of various kinds: supranational, sub-sovereign and agency (SSA), municipal, corporate, financial as well as covered bonds. To build this synthetic conventional bond, for each green bond, we search for the two conventional bonds with the closest maturity from the same issuer, having exactly the same characteristics[5]: they all have the same currency, rating, bond structure, seniority, collateral and coupon type. Since the maturities cannot be equal, we collect conventional bonds with a maturity which is neither two years lower nor two years greater than the green bond's maturity. The difference in maturity is limited in this way in order to obtain a more accurate approximation of the equivalent synthetic conventional bond yield. The other difference between the two categories of bonds is their liquidity, which can be assessed from either the issued amount or the issuance date (see Bao et al. (2011) and Houweling et al. (2005)) of the benchmark. A substantial difference in liquidity can have a considerable effect on the yield level and must therefore be limited. Here again, to ensure a fair approximation, we restrict the eligible conventional bonds to those with an issued amount of less than four times the green

[5] Since an issuer can emit various bonds of different kinds or seniority levels, thus having different ratings, we make sure that the rating is the same.

bond's issued amount and greater than one quarter of this amount[6]. We also restrict the range of conventional bonds to those with an issue date which is six years earlier or six years later than the green bond's issue date[7]. Any green bonds with which less than two of the corresponding conventional bonds comply with these requirements is excluded from the database. Among the 161 green bonds stemming from this selection process, we lastly exclude the twenty green bonds which are high yield bonds (2 bonds) or non rated bonds (7 bonds), those which do not have a fix coupon (5 bonds), and those which are non bullet (4 bonds) or non senior bonds (9 bonds)[8]. We therefore focus on the 141 remaining investment grade senior bullet fixed-coupon bonds.

In the second step, 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 bid and ask yields[9] 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 30, 2016. The data sources used for this purpose are Bloomberg BGN and BVAL[10], which provide end of day market prices and yields as well as all the features of the bonds. As green bonds are not all listed in TRACE, we cannot take advantage here of the richness of this source, especially as regards 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

[6]By doing so, we get an average issued amount for green bonds of USD 260 million (see Table 10) which sets an average cap of the issued amount for conventional bonds at around USD 1 billion and an average floor at USD 65 million below which we fall distinctly into the private placements universe.

[7]The threshold of difference in date of issuance inducing a difference in liquidity have been set at different levels depending on the authors (1 year for Elton et al. (2004), 2 years for Alexander et al. (2000) and up to 2 years for Houweling et al. (2005)). In order to eliminate old issues without ending up with a too narrow sample, we set the threshold limit at 6 years. The residual difference in liquidity will be controlled through the empirical methodology (see section 4).

[8]Note that some bonds can have several of these features at the same time, which explains why the sum of all these bonds is not equal to 20.

[9]Contrary to the price, where the bid is lower than the ask, the bid yield is higher than the ask yield.

[10]Bloomberg BGN is a real time composite based on multiple contributors' market prices. Bloomberg BVAL gives transparent, defensible bond prices at various liquidity levels, combining market data with model pricing and a calibration procedure.

our panel. We then interpolate or extrapolate[11] the two conventional bonds yields linearly at the green bond maturity date to obtain a synthetic conventional bond yield which thus shows exactly the same properties as the green bond, except for the difference in liquidity. Because of the linear interpolation or extrapolation, this method differs slightly from that used in Helwege et al. (2014), where the closest bond is selected, which gives rise to a tiny maturity bias.

The constitution of the database is pursued 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 $i$ ask yield, respectively, on day $t$. We take $\Delta\tilde{y}_{i,t} = y^{GB}_{i,t} - \tilde{y}^{CB}_{i,t}$. With a view to filtering the database, we also define $\Delta\%\tilde{y}_{i,t} = \frac{y^{GB}_{i,t} - \tilde{y}^{CB}_{i,t}}{|\tilde{y}^{CB}_{i,t}|}$, which must be regarded as a relative change[12]: this is the amount by which the green bond yield is greater or lower than the equivalent conventional bond yield, expressed as a percentage of the latter, without any liquidity control.

The panel is finalized by applying two filters to make the data more robust. The filter Bernoth et al. (2012) is applied to eliminate any transactions where the bond price exceeds both the previous and following prices by more than 20% and those where it is lower than these prices by the same amount. In the present case, none of the transactions have to be removed. The transactions are then winsorized below the 2.5% and above the 97.5% percentile, based on the distribution of the average $(\Delta\%\tilde{y}_{i,t})_t$ obtained with each bond $i$. Six outlier bonds – three on each side of the distribution, which are particularly remote from the rest of the distribution, are thus removed, leaving us with 135 remaining green bonds[13], constituting the final 43,445-line unbalanced panel to work on. This sample accounts for one fifth of the global universe and focuses on the most active issuers[14]. In

[11]If the green bond maturity is shorter or longer than both conventional bonds' maturities, we extrapolate the conventional bond yields linearly to obtain the green bond yield. Otherwise, we interpolate the two conventional bonds yields linearly.

[12]Here we divide the difference by the absolute value of $\tilde{y}^{CB}_{i,t}$ so as to keep the partial order when dealing with negative yields: for instance, we want this ratio to be positive if the green bond yield is worth -1% and the conventional bond yield is worth -1.20%. $\Delta\%\tilde{y}_{96,654} = 4.05\%$ therefore means that that green bond 96's ask yield is 4.05% greater than that of the conventional bond 96's ask yield on day 654.

[13]See Supplementary Material for a detailed list.

[14]The 135 green bonds of the sample are the one for which we managed to find two very similar conventional bonds. The issuers are mainly among the most active issuers of bonds in the market.

this panel, the earliest information dates back to April 23, 2012 and the latest information is dated December 30, 2016.

With this approach, all the unobservable factors common to both bonds in the matched pairs are therefore removed and the liquidity bias is greatly reduced: the average (respectively the median) value of the green bonds issued is USD 260.7 million (resp. USD 129.6 million), while that of the conventional bonds is USD 583 million (resp. USD 158.7 million) in the case of the first one and USD 411.4 (resp. USD 159.1 million) in that of the second one.
The characteristics of all the green bonds and conventional bonds in the database are presented in Table 1. The average number of trading days covered by the 135 pairs of bonds is 322 and the maximum is 1186, from the issue date to December 30, 2016. Significant variations are observed in the yield levels, which showed up mainly between the various issue currencies, i.e. across the corresponding rate and credit curves (see Table 8): for example, while the average AAA green bond yield in Brazilian Real is 11.18%, the average AAA green bond yield in Euros is only 0.39%.

[TABLE 1 ABOUT HERE]

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 65% negative values, giving an average of -6 bps[15] and a median value of -2 bps. 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.

[15]Note that one cannot infer the -6 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 on $t$ of the green bonds yields and the conventional bonds yields. The same applies to the medians and quartiles.

# 4 Empirical methodology

## 4.1 The model

### 4.1.1 Step 1: The green bond premium

The first step in the procedure presented here is to determine whether there is a green bond premium, i.e., whether a green bond is cheaper or more expensive than a completely equivalent conventional bond.

The difference in yield between a green bond and the equivalent conventional bond, $\Delta\tilde{y}_{i,t}$, still shows a slight liquidity bias (see Table 10). To overcome this problem, we design a proxy $\Delta\text{Liquidity}_{i,t}$ reflecting the difference in liquidity: $\Delta\text{Liquidity}_{i,t}$ is defined as the difference between a green bond and a conventional bond's liquidity indicator:

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

Since the synthetic conventional bonds are based here on the two closest conventional bonds (CB1 and CB2), the conventional bond's liquidity proxy is defined as the distance-weighted average of the liquidity proxies of CB1 and CB2. In practical terms, let $d_1 = |\text{Green Bond maturity - CB1 maturity}|$ and $d_2 = |\text{Green Bond maturity - CB2 maturity}|$. The synthetic conventional bond's liquidity proxy will therefore be:

$$\text{Liquidity}_{i,t}^{CB} = \frac{d_2}{d_1+d_2}\text{Liquidity}_{i,t}^{CB1} + \frac{d_1}{d_1+d_2}\text{Liquidity}_{i,t}^{CB2} \tag{2}$$

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

$$\Delta\tilde{y}_{i,t} = p_i + \beta\Delta\text{Liquidity}_{i,t} + \varepsilon_{i,t}, \text{ with } \varepsilon_{i,t} \text{ being the error term} \tag{3}$$

To estimate $p_i$, we use a fixed effect *Within* (FE) regression 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. In addition, these data do not hold for a broader category but give the characteristics of a specific bond. From the technical point of view, strict exogeneity holds (see section 5) and ensures unbiasedness and consistency of the estimator. In addition, the fact that we do not require the difference in liquidity proxy to be uncorrelated with the unobserved specific effect makes for a wide range of potential control parameters. However, to ensure the full rank condition, we limit the proxies to those which vary with time.

In terms of the efficiency of the FE estimator, several individual effect tests and a Hausman test are performed in order to check the efficiency of the FE estimator. In addition, controlling the difference in yields by the difference in liquidities prevents the occurrence of any simultaneity effects: the difference between two yields does not have any retroactive effects 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 Fixed Effect Generalized Least Squares (FEGLS) estimator [16] (intra-group heteroscedasticity) and a Fixed Effect estimator with an Arellano estimator[17] of the covariance matrix (inter-group heteroscedasticity) which complete the efficiency analysis.

This whole procedure enables us to control the liquidity in two ways. First, by constructing the database, we limit the differences in liquidity. Secondly, the residual liquidity bias is controlled via the fixed effect regression in order to isolate and estimate the unobserved bonds' specific heterogeneity $\widehat{p_i}$, which is the estimated green bond premium.

[16] This estimator, which was first introduced by Kiefer (1980), has been thoroughly documented in Wooldridge (2010). This is a useful procedure when $\mathbb{E}(\varepsilon_i\varepsilon_i'|x_i,p_i) \neq \mathbb{E}(\varepsilon_i\varepsilon_i')$ or when $\mathbb{E}(\varepsilon_i\varepsilon_i') \neq \sigma_\varepsilon^2\mathbb{I}_T$, where $x_i$ is the vector of independent variables. We assume that $\mathbb{E}(\varepsilon_i\varepsilon_i'|x_i,p_i) = \Lambda$ a $T \times T$ positive definite matrix.

[17] The White (see Green, W.H. (2003) and Wooldridge (2010)) and Arellano (see Arellano (1987)) estimators allow for heteroscedasticity across groups: the full covariance matrix of errors is $I_n \otimes \Omega_i$. However, while the White estimator do not allow for serial correlation, the Arellano estimator allows for a general structure taking into account any serial correlation.

#### 4.1.2 Step 2: The determinants of the green premium

Since the green bond premium may not be stable across the bonds, the determinants of the green bond premium are assessed in the second step. The estimation is based on both the structure of the curve (*Structural part*) and the specific features of each bond (*Variable part*): the *Structural part* makes the premium a linear function of the yield curve and the *Variable part* makes the premium depend on the specific characteristics of the bond.

We also examine two different types of specification: (i) a homogeneous and (ii) a heterogeneous dependence structure across all currencies.

*(i) Homogeneous dependence structure across currencies*

We consider the following specification where the effects of the rating, the maturity, the issued amount and the group to which the bond belongs are the same in all currencies. Taking $\eta_i$ to denote the error term, we set:

$$\begin{aligned}\widehat{p}_i = & \overbrace{\alpha_0 + \alpha_1 \text{Yield}_i}^{\text{Structural part}} + \overbrace{\alpha_{2,1}\text{Issued Amount}_i + \alpha_{2,2}\text{Issued Amount}_i^2 + \alpha_{3,1}\text{Maturity}_i + \alpha_{3,2}\text{Maturity}_i^2}^{\text{Variable part}} \\ & \underbrace{+ \sum_{j=1}^{p} \alpha_{4,rating_j} 1_{rating_j} + \sum_{j=1}^{q} \alpha_{5,currency_j} 1_{currency_j} + \sum_{j=1}^{r} \alpha_{6,group_j} 1_{group_j}}_{\text{Variable part}} + \eta_i \end{aligned} \quad (4)$$

*(ii) Heterogeneous dependence structure across currencies*

For each currency CUR, we also consider the specification where the effects of the rating, the maturity, the issued amount and the group to which the bond belongs can vary across currencies.

$$\begin{aligned}\widehat{p}_i = & \overbrace{\alpha_{CUR,0} + \alpha_{CUR,1} \text{Yield}_i}^{\text{Structural part}} + \overbrace{\alpha_{CUR,2,1}\text{Issued Amount}_i + \alpha_{CUR,2,2}\text{Issued Amount}_i^2}^{\text{Variable part}} \\ & \underbrace{+ + \alpha_{CUR,3,1}\text{Maturity}_i + \alpha_{CUR,3,2}\text{Maturity}_i^2 + \sum_{j=1}^{p} \alpha_{CUR,4,rating_j} 1_{rating_j} + \sum_{j=1}^{q} \alpha_{CUR,5,group_j} 1_{group_j} + \eta_i}_{\text{Variable part}} \end{aligned}$$

(5)

More specifically, we express the maturity in years and the issued amount[18] in USD billions with the reference date of December 30, 2016 and the exchange rate which applied on that date. The rating[19] of the bond can be AAA, AA, A or BBB. The variables standing for the currency and the group are qualitative variables. We use the level 1 Bloomberg classification (BICS level 1) for the group breakdown procedure, which leaves us, in the case of the present sample, with three main categories: (i) "Government", which includes municipalities, regional and sovereign agencies, national, supranational and development banks, (ii) "Utilities", and (iii) "Financials" which encompasses non-public banks and financial services. Lastly, since the possible presence of a non-linear relationship cannot be ruled out, we also examine the independent variables $\text{Maturity}^2$ and $\text{Issued Amount}^2$.

## *4.2 The liquidity-control variables*

The use of liquidity proxies makes it possible to control the difference in liquidity between a green bond and the conventional bond using the regression (3). Given the data sources and the type of regression, the liquidity proxies which can be used here are subject to three constraints. First, since we cannot use intraday data to calculate intraday liquidity indicators such as the Amihud measure, Range measure or intraday Roll and Gamma measure, for example, we focus on low frequency data. Secondly, contrary 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. Thirdly, since we perform a Within regression, any variable that does not change over time with a given bond is not suitable. Proxies such as the issued amount, the issue date or off-the-run versus on-the-run indicators therefore cannot be used.

[18] It is worth noting that controlling the difference in liquidity between green bonds and conventional bonds does not prevent the liquidity from having an impact on the green bond premium.

[19] 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.

Two liquidity proxies are eventually selected: the yield bid-ask spread (BA) and the *Zero trading day* measure (ZTD). The BA is the difference between the ask yield and the bid yield. We use the closing yield bid-ask spread instead of the price bid-ask spread in order to have homogeneous variables in the regression (3). Hence, we are consistent with Fong et al. (2017) who show, through an extensive analysis of the quality of high- and low-frequency liquidity proxies, that the closing percent quoted spread is the best low-frequency liquidity proxy. The zero trading day is a variable that equals 1 if the bond price does not vary during a trading day and zero otherwise.

Once these indices have been determined, $\Delta\text{Liquidity}_{i,t}$ is calculated with equations (1) and (2). The distribution of the average value of the three liquidity proxies applied to each pair of bonds is presented in Table 2.

[TABLE 2 ABOUT HERE]

The statistics show that the variables are concentrated around zero and a low standard deviation is observed. This indicates that the first liquidity control on the amounts issued and the date of issuance in the data construction procedure yields satisfactory results.

# 5 The green bond premium

## *5.1 A mostly negative green bond premium*

The aim of the first step in the analysis is to estimate the green bond premium in terms of its sign and its magnitude. In both the regressions of $\Delta\tilde{y}_{i,t}$ on $\Delta$BA and $\Delta$ZTD, the presence of an unobserved heterogeneous effect is confirmed via an F-test, a Wooldridge test, a Breusch-Pagan test and a Honda test[20]. We also perform a Hausman test and establish that the Within estimator is more robust than the Random Effect (RE) in the regression performed on $\Delta$BA, contrary to that performed on $\Delta$ZTD. Both estimators are unbiased and consistent: although it is intuitive that the

[20] See Supplementary material for the detail of all the tests performed in this article.

idiosyncratic error term may not be correlated with either the previous or forthcoming differences in liquidity (neither feedback effect, nor financial periodiciy), we confirm this hypothesis through a Su et al. (2016)'s test which strongly evidences $H_0$ with high P Values[21]. This estimation is all the more satisfactory as the average number of days is greater than the number of bonds (see Goldstein (2003)) and $\Delta\text{Liquidity}_{i,t}$ varies substantially with time.
We also run Breusch-Godfrey, Durbin Watson and Wooldridge tests, all of which indicate the existence of serial correlation with both regressions. In addition, a Breusch-Pagan test shows the presence of heteroscedasticity. In order to study the serial correlation and the intra-group heteroscedasticity, we therefore complete the FE regression with an FEGLS regression (see Wooldridge (2010)). For maximum efficiency, this method requires $N >> T$, which is not the case here since the number of green bonds available is not sufficiently large. We therefore analyze both the FE and FEGLS regressions performed in the first step in order to compare the results.

The FE and FEGLS panel regressions of the difference in yield between the green bonds and their equivalent synthetic conventional bonds on the difference in liquidity give similar results and significance (see Table 3). Although the four regressions evidence a satisfactory $R^2$ equal to 26% and 27%, the bid-ask spread proxy used to control the difference in liquidity proves to be the most significant. A Fixed Effect estimator with an Arellano estimator of the covariance matrix, which controls the serial correlation and the inter-group heteroscedasticity, achieves the same result. Therefore, keeping the conventional bond bid-ask spread constant, a 1-bp increase in the yield bid-ask spread of the green bond induces a -0.88-bp decrease in $\Delta\tilde{y}_{i,t}$. As regards the zero-trading day index, when no trading activity occurs 10% of the time on the green bond and trading on the conventional bond occurs everyday, $\Delta\tilde{y}_{i,t}$ increases by 0.17 bp. It is worth noting that the sign of $\widehat{\beta}$ differs between the two regressions because these two proxies do not capture the same information about the liquidity: ΔBA expresses the difference in cumulative buying and

[21] We test various hypotheses for ΔBA and ΔZTD via a bootstrap procedure of 1000 samples: Strict exogeneity for the case of one and two days lag (P Values are equal to 90% and 67%, respectively), for the case of one and two days lag as well as one an two days lead (P Values are equal to 30% and 66%, respectively).

selling pressure, whereas ΔZTD reflects the difference in scarcity of the trading activity.

[TABLE 3 ABOUT HERE]

More important for the present purposes is the value of the 135 fixed effects $p_i$ constituting each of the green bonds' premia. The four families of estimated green bond premia, denoted ($\widehat{p_i}^{FEGLS}$(BA), $\widehat{p_i}^{FE}$(BA), $\widehat{p_i}^{FEGLS}$(ZTD), and $\widehat{p_i}^{FE}$(ZTD)) are detailed in the Supplementary material. These values are very similar in all four regressions: the sum of the absolute values of the fixed effects is $-0.003\%$ lower with $\widehat{p_i}^{FEGLS}$(BA) than with $\widehat{p_i}^{FE}$(BA), 0.000001% greater with $\widehat{p_i}^{FEGLS}$(ZTD) than with $\widehat{p_i}^{FE}$(ZTD) and 7.95% greater with $\widehat{p_i}^{FEGLS}$(BA) than with $\widehat{p_i}^{FEGLS}$(ZTD). It is therefore decided to pursue our analysis with $\widehat{p_i}^{FEGLS}$(BA) (denoted $\widehat{p_i}$ hereafter), since the regression on ΔBA is the most significant and $\widehat{p_i}^{FEGLS}$(BA) is equal to $\widehat{p_i}^{FE}$(BA) at a $10^{-4}$ threshold.

The distribution of the green bond premia ranges from -2.66% to +2.39% with a mean and a median value of -8.23 bps and -1.64 bps, respectively, with the ΔBA control (see Table 4): 64% of the premia are negative and the amplitudes are greater on the downside than on the upside (see Figure 1a). It is worth noting that the extreme values of $\widehat{p_i}$ appear for currencies presenting a high yield (such as BRL, IDR or INR): Figure 1b shows that the distribution of $\widehat{p_i}$ divided by the yield at December 31, 2016[22] has a much lower standard deviation (28%) than the distribution of $\widehat{p_i}$ (59%).

[TABLE 4 ABOUT HERE]

[FIGURES 1a AND 1b ABOUT HERE]

It should also be noted that if we had chosen the closest conventional bond and had not controlled by the difference in liquidity, the average green bond yield would have been slightly greater than the average conventional bond yield (see Table 1). Although the average $\widehat{p_i}$ (-8 bps) is only 2 bps lower

[22]The three bonds with a ratio greater than 100% or lower than -100% have a yield very close to zero.

than the average $\Delta\tilde{y}_i$ (-6 bps), it is necessary not to skip this step because the difference between the amount of green bonds and the synthetic conventional bonds issued may differ up to four-fold. In addition, from the point of view of developing a general method, the control performed in this first step is necessary and may have even greater effects than those observed here, depending on the data used.

Lastly, we test the significance of the negative green bond premium: since the Central limit theorem tells us that the law of $\frac{\sqrt{n}}{\sigma}\sum_{i=1}^{n}\widehat{p_i}$ converges towards a standard normal distribution, we test $H_0 : \text{Mean}(\widehat{p_i}) = 0$. We observe that we reject $H_0$ - i.e. the green bond premium differs from zero - on the whole database at a 90% confidence level. This premium is more significantly negative in various market segments. For example, focusing on bonds with an issued amount of over USD 100 million, all the EUR-denominated (resp. USD-denominated) bonds carry a -2 bps (resp. -5 bps) average premium which differs significantly from zero at a 90% (resp. 95%) confidence level. More interestingly, the EUR-denominated (resp. USD-denominated) bonds with a rating strictly below AAA have a -4 bps (resp. -9 bps) average green bond premium which differs significantly from zero at a 99% (resp. 90%) confidence level. We thus provide evidence that on average, there exists a significantly negative premium inherent to green bonds: in the whole sample, the bond holder pays an average premium of 8 bps for the green bond label in the secondary market.

[TABLE 5 ABOUT HERE]

## 5.2 The determinants of a 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 under investigation. Based on step 2, we consider a homogeneous dependence structure in the whole sample of bonds (equation (4)) and a heterogeneous dependence structure across currencies focusing here on EUR and USD (equation (5)).

For the sake of a robust analysis, we exclude bonds and private placements with a small issued amount, i.e. less than USD 100 million, which leaves us with 71 green bonds versus 135 in the whole sample (equation (4)), 25 EUR bonds versus 26 in the whole subsample and 26 USD bonds versus 29 in the whole subsample (equation (5)). We lastly exclude two outlier bonds from the whole sample with an issued amount greater than USD 100 million[23], giving a total number of 69 green bonds for the regression (4).

We present the regressions for $\widehat{p}_i^{FEGLS}(\text{BA})$ as the dependent variable, i.e. the green bond premia stemming from the panel regression controlled by the bid-ask spread, but the results are similar to those obtained with $\widehat{p}_i^{FE}(\text{BA})$, $\widehat{p}_i^{FEGLS}(\text{ZTD})$ and $\widehat{p}_i^{FE}(\text{ZTD})$ (see Table 4). We focus specifically on combinations of independent variables that have an effect in each of the three regressions. For example, there is no evidence of a quadratic effect of the maturity, the issued amount or the rating in the case of the USD bond subsample, contrary to what occurs with the EUR bond subsample. We therefore examine 6 specifications ((a) to (f)) for the first regression performed on the whole sample and 9 specifications for each of the last two regressions performed on the EUR ((g) to (o)) and USD ((p) to (x)) subsamples.

The results of the Breusch-Pagan tests and the GVIF analysis performed on each of the 24 specifications considered ((a) to (x)) show that no heteroscedasticity or multicolinearity issues are involved. The Durbin-Watson tests and ACF analysis[24] show, however, the existence of an AR(1) serial correlation in the case of specifications (g), (h) and (t). Although the OLS estimator is unbiased, it is no longer efficient. We therefore run a GLS regression with an AR(1)-structure of the variance-covariance matrix of the error term on specifications (g), (h) and (t) and an OLS regression on the remaining specifications. The first regression (equation (4)) performed on the whole sample explains one fourth of the total variance of the green bond premium (see Table 11), whereas the last two regressions (equation (5)) performed on the EUR and the USD subsamples

[23] We exclude the only BRL bond and the only INR bond which made the quality of the estimation artificially high according to the $R^2$.

[24] See Supplementary Material for a detailed analysis of the tests performed.

explain 46.1% and 41.6% of the total variance, respectively (see Tables 6 and 7).

[TABLE 6 ABOUT HERE]

[TABLE 7 ABOUT HERE]

In terms of the results obtained on the whole sample via equation (4), the additional effect of the currency is not significant (see specification (a)). The *Structural part* of the equation plays a significant role: the premium decreases by 1.7 to 1.8 bps every 1% yield increment (see (b), (d), (e) and (f)). The only *Variable part* having a significant effect is the group to which the bond belongs: when not controlling for the rating, Financial bonds show a 7.3 to 7.4 bps premium below the reference level, which is that of Government-related bonds (see (b), (d) and (e)). However, the strong hypothesis of the homogeneous dependence structure across a large number of currencies limits the accuracy of the estimated effects.

Focusing on the EUR and USD subsamples in equation (5), it emerges that the green bond premium vary considerably with the currency of issuance. As far as EUR green bonds are concerned, the structural effect is very weak and the main determinants of the premium are the group, the rating and the size of the issuance (see (o)). First, compared to Government-relted bonds, Financials and Utilities premia involve a negative effect of -5.2 bps and -2,7 bps, respectively. In addition, the AA premium is 3.1 bps below the AAA premium while the A and BBB are slightly greater than the AAA premium by 1.1 bps and 2.4 bps, respectively. Lastly, the greater the issued amount, the higher the premium: the premium on a bond with an issued amount of USD 2 billion is 1.8 bps (resp. 3.5 bps) greater than that on a bond with an issued amount of USD 1 billion (resp. USD 500 million). With regard to the USD bond premium, it is driven by three main determinants (see (x)): a structural effect which decreases the premium by 7.6 bps per 1% increase in the yield, a positive effect of decreasing the rating - which increases the premium with respect to AAA bonds by 8.1 bps, 19.1 bps and 21.4 bps for AA, A and BBB bonds respectively - compensated by a strong negative -23.7-bps effect of Financial bonds versus Government-related bonds.

By linking these findings with the literature on liquidity premium, it is interesting to note that the illiquidity effect on credit spreads also varies with 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 A. (2016)), the issued amount (Longstaff et al. (2005)) and is greater for corporate bonds (Longstaff et al. (2005)).

Focusing on specifications (o) and (x), we then express the green bond premia in absolute terms depending on the rating, the issued amount and the group in the case of EUR bonds and depending on the rating, the yield level and the group in that of USD bonds. The heatmaps in Figure 2 give the green bond premia, which decrease for corporate bonds and as the rating improves. Moreover, the premia diminish as the issued amount declines for EUR bonds and as the yield rises for USD bonds. They are *de facto* all negative in the case of EUR and USD corporate bonds. For example, the yield of a EUR A Utility green bond with an issued amount of USD 500 million is 7 bps lower, than that of an equivalent conventional bond. However, while Government-related EUR green bond premia are mostly negative, USD Government-related premia are balanced around zero. Additionally, the amplitude of the USD premia is wider than that of EUR premia because, contrary to the latter, the former benefit from a higher rate environment notably provided by the Federal Reserve recent *tapering*.

These findings are consistent but nuance several first works that addressed this issue. As suspected by Barclays (2015) and Bloomberg (2017), though to a much lesser extent, we show the existence of a negative premium in most cases for EUR and USD bonds. Moreover, in some specific cases such as Government-related USD bonds with a low yield, the premium happens to be positive (see Karpf and Mandel (2017)).

[FIGURE 2 ABOUT HERE]

In the final step, thanks to 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 particularly useful for investors as well as for issuers since few green bond benchmarks have been issued so far. Figure 3 presents the reconstituted green bond curve obtained by performing regression (o) on

EUR bonds and regression (x) on USD bonds, as well as the conventional bond curve for twelve different issuers. The quality of the fit obtained on the whole sample is satisfactory. However, the green bond curve does not always exactly intersect with the green bond market yields, which are indicated with a blue asterisk in the graph, for three main reasons. First, the green bond premia we calculate and explain here are long term green premia which reflect the average distortion since their inception. In order 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 larger the number of data available for estimating the green bond premium, the closer the fit will be.

[FIGURE 3 ABOUT HERE]

# 6 Robustness checks

In the first step of our robustness checks, we examine whether a negative premium may reflect the fact that a lower level of risk is involved in a green bond than a conventional bond. We calculate the annualized volatility during the period of interest in the case of both green bonds and the closest conventional bonds (CB1) and take the difference between the members of each pair. The average difference in the case of the 135 pairs is found to amount to almost zero: 0.2%. Adding the difference in volatility as an independent variable to regressions (a), (o) and (x) yields no significance (P-Value = 66%, 88% and 66%, respectively), which indicates that the green bond premium differs from a risk premium (see Table 12).

Another main issue which arises is the question as to whether or not a green bond premium remains stable with time. A fixed time effect is added to the individual effect in the first regression procedure via a Within two-way model, taking the bid-ask spread as the liquidity-control variable. The estimated bid-ask spread parameter is found to be significant and almost equal to the parameter estimated via the individual fixed effect regression (-0.883). Yet the individual time effect is significant during only 7% of the 1222 days considered, which means that there might not be any strong daily time fixed effect involved in the green bond premium.

However, upon applying the same regression procedure to the whole range of data on a monthly basis over the whole year 2016, we find the green bond premium to be variable[25] although it was almost always negative on average. An FEGLS regression is performed month by month from January 2016 to December 2016 and the mean, the median and the quartiles of the green bond premia are calculated. Focusing on EUR and USD bonds with an issued amount greater than USD 100 million, we establish that the median and average green bond premia are almost always negative, especially in the case of Investment Grade bonds with a rating below AAA (see Figure 4): the average value ranges mainly between -5 bps and 0 bps in the case of EUR bonds, around -5 bps in the case of EUR bonds with a lower rating than AAA, between -15 bps and +5bps in that of USD bonds and between -30 bps and +10 bps in that of USD bonds with a lower rating than AAA.

[FIGURE 4 ABOUT HERE]

The second regression procedure is then performed on the bonds in EUR ((o)) and USD ((x)) currencies in order to monitor the dynamics of the determinants of the green bond premium every month from January 2016 onwards (see Tables 14 and 13). With both currencies, although the effects are volatile on a monthly basis, the signs of the effects are often the same as those observed during the whole time period. It is worth noting that the robustness checks on a monthly basis are performed on a rather small sample and fewer bonds are therefore included than in the main regression. The information involved is therefore quite different from that involved in the main regressions, which mostly explains the discrepancies observed between the results.

A further potential concern is whether the green bond premium reflects a market risk premium

[25] Interestingly, Longstaff et al. (2005), Favero et al. (2010), Huang and Huang (2012) show that the liquidity premium varies accross time.

over time. Although the daily time effect of the Within two-way regression has a low level of significance, we 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 correlation between the index daily returns and the green bonds' time effects daily returns amount to almost zero (6.2%, 1.1% and 0.4% respectively). In addition, to handle the heteroscedasticity issue, we perform a feasible general least square regression in order to explain the daily returns of the green bond's time effects by the index daily returns. Neither the S&P 500 nor the Eurostoxx 50 nor the MSCI World show significant effects since the P-Values amount to 25%, 71% and 88%, respectively. This analysis shows that the time effect, not only have a low level of significance, but are 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 interpolation or the extrapolation performed to obtain the synthetic conventional bonds' yield from the yield of the two genuine conventional bonds CB1 and CB2 must also be addressed. If the maturities of CB1 and CB2 differ greatly from that of the green bond, the synthetic conventional bond yield is liable to be over- or under-estimated. Any green bonds showing a difference in maturity of more than one year with the closest conventional bond, CB1, are therefore excluded from the analysis in order to improve the quality of the interpolation or the extrapolation of the conventional bond yields. Six bonds are excluded for this reason. Here again, the results obtained, which are presented in Table 15, show that the green bond premia are very similar to those estimated in section 5. In addition, the effects of the variables under consideration are similar and give a comparable fit with the green bond curve. The estimations are almost equal in the case of regression (o). In the case of regression (x), the effects are comparable though less strongly pronounced: the effect of the rating is weaker, but counterbalanced by the existence of a smaller difference between Financial and Government-related bonds.

Lastly, we validated the specification of the step 2 regression, eliminating the non-linear structure of some independent variables (see Table 6 and 7) as well the cross effects that are not significant for both EUR and USD currencies.

# 7 Discussion

The negative average green bond premia found to exist in many market segments highlight the fact that the buying pressure relative to the supply capacity is greater in the case of green bonds than conventional bonds[26]. This market microstructure discrepancy can be attributed to two phenomena, which are not mutually exclusive: an excess of investment demand due to the intrinsic characteristic of green bonds, and an insufficiently large volume of bond issuances.

On the one hand, a negative premium due to an excess of investment demand in green bond supports the findings of the stakeholder theory, according to which a better environmental performance decreases the cost of capital. One of the channels involved is the increase in the size of the bondholder base (Heinkel et al. (2001), Ge and Liu (2015) and Bauer and Hann (2014)), which exerts a greater downward pressure on green bond yields relative to conventional bond yields. This situation, fed by public and private initiatives designed to redirect investments towards low carbon assets, reflects the strong interest of investors willing to fund the environmental transition in green bonds. On the other hand, a negative premium due to an insufficient volume of bond issuances bolsters the qualitative conclusions of I4CE (2017), according to which two main types of barriers at the issuer's level obstruct the expansion of the green bond market. Those of the first type are barriers to the development of the green project investment pipeline, which can be due to low carbon pricing, insufficient fiscal incentives to making green investments, lack of Power Purchase Agreements for renewable electricity in some markets, uncertainty on the evolution of feed-in tariffs or large companies having difficulty in shifting their strategy to low-environmental impact projects. Those of the second type are barriers to green bond labelling due to higher costs (external review, monitoring the use of proceeds, etc.), higher legal and reputational costs if commitments are not

[26] See Arrow (1959), Debreu (1959) for the seminal theoretical framework and Greenwood and Vayanos (2010), Greenwood and Vayanos (2014), Krishnamurthyn and Vissing-Jorgensen (2012) for the case of the bond market.

achieved and a lack of awareness of the benefits of issuing green bonds.

As a matter of fact, the negative green bond premia reveal a favourable situation for green bond issuers they could take advantage of. Not only it highlights the capacity of the market to absorb more green debt issuance, but the secondary market structure points to the potential for offering a primary yield which is slightly lower than that observed on the conventional bond curve. These conditions are all the more valuable for companies that have the possibility to prioritize the launching of a green project, instead of a conventional project, due to a lower cost of capital especially as green bonds are currently issued at a comparable yield to that of conventional bonds with the same characteristics originating from the same issuer (OECD (2017)).
Nevertheless, this situation remains a problem for three reasons. First, it reveals the structural lack of green projects and infrastructures launched by the industry. Second, a negative green bond premium subdues the appetite of investors that are not compelled to dedicate part of their balance sheets to the purchase of green assets. Such is the case for most of the traditional pension funds and insurance companies of which the investment commitee has not set up a binding floor for green assets in the strategic asset allocation. In addition to winding down the funding of low-carbon projects, a negative premium would increase the concentration of green bond risks among the few existing green investors, and thus potentially hike up the level of systemic risk. Lastly, such a concentration would be detrimental in terms of the access to green funds for retail investors. Allowing a wide range of institutional investors to strenghten their green bonds allocation would reach a broader retail investor base that could opt for green funds and therefore catalyse the debt financing of the environmental transition.

The opportunity to increase the issuance of green bonds, which still accounted for less than 0.10% of the global outstanding debt and 0.20% of the yearly issued debt in 2015 (OECD (2017)), is not only a major issue but is also consistent with political ambitions and financial players' recommendations. A consortium of European sustainable finance associations and institutions released a report in October 2016 in which it was recommended in particular that the European Commission should "support the rapid development of robust, fully developed and widely accepted industry standards for green bonds" (E3G et al. (2016)). Policy makers can therefore play a crucial role by providing green project developers with more attractive conditions and unlocking the full potential of the green bond market. For example, national and supranational authorities could help to draw up a precisely defined framework for green bond requirements and streamline the approval process in order to increase the flow of low-carbon projects. Indeed, in 2016, green bonds accounted for only 17% of the USD 694 billion climate-aligned bonds universe (Climate Bonds Initiative (2016)) that gathers potential candidates for a green bond label. Fostering risk pooling, through ABS in particular, would also enable minor players to enter the green bond market. Another pathway would consist in reducing the risks involved in green bonds via credit enhancement by public institutions (such as the EIB, the EBRD or the World Bank). Lastly, governments could set up a beneficial tax regime for green bond issuances in order to stimulate and support the green bond market. This fiscal support could also be implemented at the level of green project (renewable energy infrastructures, clean transportation, low-energy buildings, etc.) to indirectly boost the green corporate bond issuances.

# 8 Conclusion

At a time of low carbon as well as fossil fuel energy prices, green bonds are highly attractive financial instruments which foster the environmental transition, while enabling low-carbon project holders to expand their funding capacity. In this paper, we analyze the yield of a green bond versus that of an equivalent synthetic non-green bond through a matching method. To ensure high-quality data, we study a sample accounting for one fifth of the green bonds issued worldwide until December 2016 by the most active issuers. The green bond premium is defined as the difference in yield between these two bonds after controlling for the difference in liquidity. The main objective of this article is to determine the value of the green bond premium and to explain it.

We show that, since the green bonds of interest were first issued, the average green bond premium turns out to be significantly negative and equal to -8 bps in the whole sample of Investment Grade bonds, -5 bps and -2 bps in the USD and the EUR bonds with an issued amount greater than USD 100 million, respectively, and -9 bps and -4 bps in the subsamples of below-AAA USD and EUR bonds, respectively. In addition, the average and median premia remained mostly negative throughout the whole year 2016. We also establish that the group, the rating and the issued amount are major drivers of the green bond premium on EUR bonds: Financial bonds have a lower premium than Government-related bonds ; moreover, the riskier a bond or the lower the issued amount, the greater the negative premium will be. With USD bonds however, the premium decreases with the level of the yield and is substantially lower for Financial than Government-related bonds, although this effect is counterbalanced by the positive effect of a lower rating.

This study has several financial and political implications. First, it provides issuers as well as investors with a simple method of pricing newly issued green bond benchmarks. Secondly, it shows that there is a shortage of green bonds relative to the investment demand and calls for operational and fiscal measures to increase the pipeline of green bonds issued. It also suggests that current investors can still absorb a yield at issuance which is slightly lower than that suggested by the conventional curve.

The methodology presented in this paper has been applied in the bank report Natixis (2017) to analyze the existence of a negative premium for European Investment Bank green bonds. It is shown that there has been a growing negative premium (up to -8 bps), since January 2017, for the four main green bonds issued.

The main limitations of this study are due to the quality of the data. Since bonds – and *a fortiori* corporate bonds – are not frequently traded, a bond yield sometimes does not accurately reflect its fair value. It can also be said that the larger the number of green bonds issued and the longer their history, the more accurate the results of an analysis of this kind will be.

Further research on these lines could focus on pursuing the following three main aims. First, to understand the determinants of the green bond premium through a market microstructure theoretical model. Another line of research could consist in designing public supporting measures, assessing their effects on the green bond market's microstructure, and comparing the differential impacts via sensitivity scenarios. Lastly, this study could be extended in the future to bonds of other kinds, such as Social Impact bonds, with a view to drawing conclusions in terms of market microstructure and public policy.

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# Tables and Figures

| | All bonds | | | | | |
|---|---|---|---|---|---|---|
| | **Min.** | **2nd quart.** | **Median** | **Mean** | **3rd quart.** | **Max.** |
| Number of days per bond | 11 | 122 | 260 | 322 | 454 | 1 186 |
| Ask yield of the GB $y^{GB}$ | - 0.29 | 0.94 | 2.55 | 4.30 | 7.35 | 13.53 |
| Ask yield of the CB1 $y^{CB_1}$ | - 0.29 | 0.94 | 2.71 | 4.29 | 7.45 | 13.49 |
| Ask yield of the CB2 $y^{CB_2}$ | - 0.29 | 0.90 | 2.83 | 4.36 | 7.51 | 13.49 |
| Ask yield of the interp. CB $\tilde{y}^{CB}$ | - 0.35 | 0.94 | 2.74 | 4.36 | 7.40 | 13.49 |
| Yield difference % $\Delta\tilde{y}_{i,t}$ | -2.59% | -0.14% | -0.02% | -0.06% | 0.02% | 2.29% |
| Green bond maturity on Dec. 30, 2016 (in years) | 0.08 | 1.91 | 2.89 | 3.33 | 4.28 | 14.41 |
| Conventional bond 1 maturity | - 0.26 | 1.71 | 2.62 | 3.27 | 4.16 | 15.04 |
| Conventional bond 2 maturity | 0.03 | 1.44 | 2.73 | 3.11 | 4.04 | 13.41 |

Table 1 – **General characteristics of the bonds in the database**. This table gives the distribution of several variables of interest in all the 135 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 in the case of the green bond ($y^{GB}$), the two closest conventional bonds ($y^{CB_1}$ and $y^{CB_2}$) and the interpolated (or extrapolated) conventional bond ($\tilde{y}^{CB}$). The difference in yield ($\Delta\tilde{y}_{i,t}$) is the difference between the green bond ask yield and the interpolated (or extrapolated) conventional bond ask yield. In order to compare the accuracy of the interpolations (or extrapolations) this table also shows the distribution of the green bond maturities and the two closest conventional bond maturities. Note that the lowest maturity of CB2 was negative since it was prior to December 30, 2016.

| **Difference in** | **Min.** | **1st Quart** | **Median** | **Mean** | **3rd Quart.** | **Max.** | **Std. Dev** |
|---|---|---|---|---|---|---|---|
| ΔBA (in %) | -0.77 | -0.03 | 0.00 | -0.02 | 0.01 | 0.78 | 0.14 |
| ΔZTD | -21.6% | -0.4% | 0.0% | -0.2% | 0.1% | 17.6% | 2.7% |

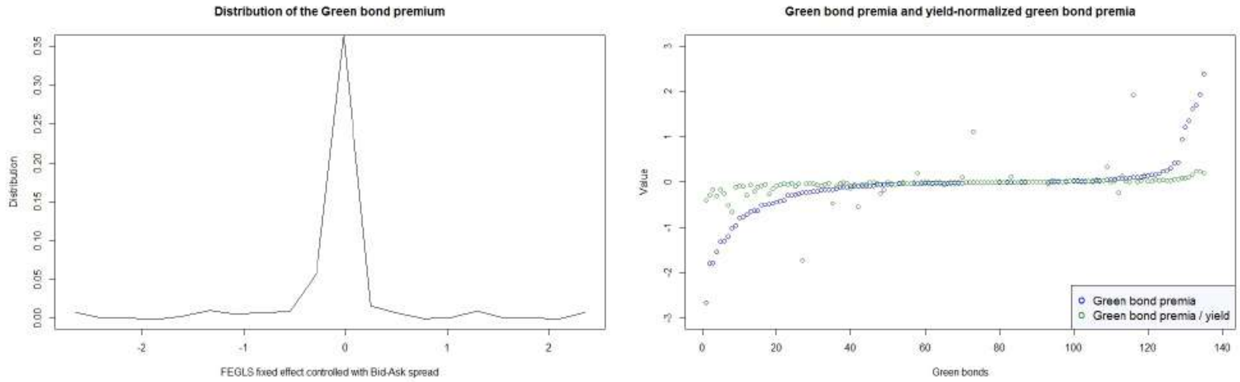
Table 2 – **Descriptive statistics of the two liquidity proxies.** This table summarizes the distribution of the two average liquidity controls. ΔBA is the average difference between the green bond bid-ask spread and the conventional bond bid-ask spread in a specific pair of bonds during the period under consideration. ΔZTD is the average difference between the percentages of non trading days of the green bond and the conventional bond during the period under consideration in the case of a specific pair of bonds. Both variables are centered around zero which illustrates the quality of the first filter used on the size of the issued amount and on the date of issuance.

| | *Dependent variable:* | | | |
|---|---|---|---|---|
| | $\Delta\tilde{y}_{i,t}$ | | | |
| | FE | FEGLS | FE | FEGLS |
| | (i) | (ii) | (iii) | (iv) |
| Bid-Ask spread | $-0.882^{***}$ | $-0.882^{***}$ | | |
| | (0.034) | (0.071) | | |
| Zero trading day | | | 0.017 | 0.017 |
| | | | (0.044) | (0.071) |
| Observations | 43,445 | 43,445 | 43,445 | 43,445 |
| Adjusted $R^2$ / Multiple $R^2$ | 0.27 | 0.27 | 0.26 | 0.26 |
| *Note:* | | | | $^{*}$p<0.1; $^{**}$p<0.05; $^{***}$p<0.01 |

Table 3 – **Results of step 1 regression.** This table gives the results of the following fixed effects in the Within ((i) and (iii)) and Generalized Least Square Within (FEGLS, (ii) and (iv)) regressions: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta\text{Liquidity}_{i,t} + \varepsilon_{i,t}$. The liquidity control parameters are $\Delta\text{BA}_{i,t}$ in equations (i) and (ii) and $\Delta\text{ZTD}_{i,t}$ in equations (iii) and (iv). Although the FEGLS regressions provide a more significant means of control than FE regressions, the estimated effect is very similar.

| | **Min.** | **1st quart.** | **Median** | **Mean** | **3rd quart.** | **Max.** |
|---|---|---|---|---|---|---|
| $\Delta\tilde{y}_i$: Average $\Delta\tilde{y}_{i,t}$ over $t$ | -2.59% | -0.14% | -0.02% | -0.06% | 0.02% | 2.29% |
| Fixed effect $\widehat{p}_i^{FE}(\Delta\text{BA})$ | -2.66% | -0.16% | -0.02% | -0.08% | 0.02% | 2.39% |
| Fixed effect $\widehat{p}_i^{FEGLS}(\Delta\text{BA})$ | -2.66% | -0.16% | -0.02% | -0.08% | 0.02% | 2.39% |
| Fixed effect $\widehat{p}_i^{FE}(\Delta\text{ZTD})$ | -2.59% | -0.14% | -0.02% | -0.06% | 0.02% | 2.29% |
| Fixed effect $\widehat{p}_i^{FEGLS}(\Delta\text{ZTD})$ | -2.59% | -0.14% | -0.02% | -0.06% | 0.02% | 2.29% |

Table 4 – **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: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta\text{Liquidity}_{i,t} + \varepsilon_{i,t}$. We observe four cases corresponding to FE and FEGLS regressions with the ΔBA and ΔZTD liquidity controls. The estimated green bond premia turn out to be all very similar in all four cases.




(a) Distribution of the green bond premia across all bonds.

(b) Green bond premia and yield-normalized green bond premia sorted across all bonds.

Figure 1 – **Green bond premia distributions.** These two figures give, across all bonds included in this study, the distribution of $\widehat{p_i}^{FEGLS}(\Delta\text{BA})$ (Figure a) and the sorted values of $\widehat{p_i}^{FEGLS}(\Delta\text{BA})$ and $\widehat{p_i}^{FEGLS}(\Delta\text{BA})/y^{GB}_{i,\text{Dec. 30, 2016}}$ (Figure b).

| | Average $\widehat{p_i}^{FEGLS}(\Delta\text{BA})$ (in %) | Significantly $\neq 0$ | Sample size |
|---|---|---|---|
| All bonds | -0,08 | Yes at 90% | 135 |
| All bonds > USD 100m | -0,02 | No | 71 |
| All bonds: AAA | -0,14 | Yes at 94% | 80 |
| All bonds > USD 100m: AAA | 0,02 | No | 38 |
| All bonds: AA + A + BBB | 0,00 | No | 55 |
| All bonds > USD 100m: AA + A + BBB | -0,06 | Yes at 99% | 33 |
| USD bonds | -0,11 | Yes at 95% | 29 |
| **USD bonds > USD 100m** | **-0,05** | **Yes at 95%** | **26** |
| USD bonds: AAA | -0,02 | No | 15 |
| USD bonds > USD 100m: AAA | -0,02 | No | 14 |
| USD bonds: AA + A + BBB | -0,20 | Yes at 95% | 14 |
| **USD bonds > USD 100m: AA + A + BBB** | **-0,09** | **Yes at 90%** | **12** |
| EUR bonds | -0,01 | No | 26 |
| **EUR bonds > USD 100m** | **-0,02** | **Yes at 90%** | **25** |
| EUR bonds: AAA | 0,01 | No | 12 |
| EUR bonds > USD 100m: AAA | 0,01 | No | 11 |
| EUR bonds: AA + A + BBB | -0,04 | Yes at 99% | 14 |
| **EUR bonds > USD 100m: AA + A + BBB** | **-0,04** | **Yes at 99%** | **14** |
| BRL bonds | 0,28 | No | 17 |
| AUD bonds | -0,23 | Yes at 95% | 12 |
| INR bonds | -0,20 | No | 18 |
| IDR bonds | -0,79 | Yes at 99% | 7 |

Table 5 – **Green bond premia in several market segments**. This table shows the average green bond premium in several market segments and the level of significance at which we rejected $H_0$ : Mean$(\widehat{p}_i) = 0$. We distinguish the sample of bonds with which the issued amount is over USD 100 million from the whole sample to keep the tiny issuances out of the analysis. For example, the average premium on Euro-denominated bonds with a rating strictly below AAA amounts to -4 bps and differs from zero with a 99% confidence level.

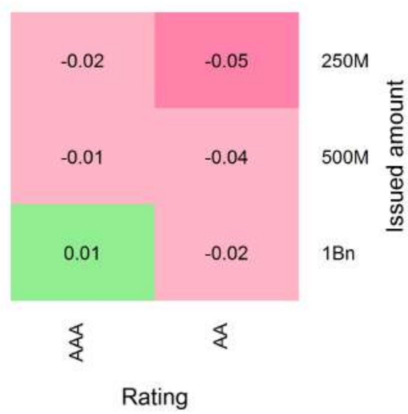
| | Dependent variable: $\widehat{p}_i^{FEGLS}$(BA) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *OLS* | *GLS* | *OLS* | *GLS* | *OLS* | *OLS* | *OLS* | *OLS* | *OLS* | *OLS* | *OLS* |
| | (g) | (g) | (h) | (h) | (i) | (j) | (k) | (l) | (m) | (n) | (o) |
| Constant | −0.008 | −0.010 | −0.015 | −0.005 | −0.079*** | 0.009 | 0.002 | 0.009 | −0.045 | −0.039 | −0.030 |
| | (0.014) | (0.017) | (0.022) | (0.022) | (0.025) | (0.012) | (0.011) | (0.012) | (0.031) | (0.032) | (0.037) |
| Yield (%) | −0.021 | −0.016 | | | | | | | | | |
| | (0.026) | (0.021) | | | | | | | | | |
| Maturity (years) | | | −0.0001 | −0.002 | | | | | | | |
| | | | (0.003) | (0.002) | | | | | | | |
| Issued amount (bn USD) | | | | | 0.095** | | | | 0.071 | 0.054 | 0.051 |
| | | | | | (0.042) | | | | (0.043) | (0.048) | (0.052) |
| Issued amount$^2$ | | | | | −0.021 | | | | −0.016 | −0.012 | −0.011 |
| | | | | | (0.013) | | | | (0.013) | (0.014) | (0.015) |
| Rating AA | | | | | | −0.061** | | −0.042 | −0.044 | | −0.031 |
| | | | | | | (0.027) | | (0.031) | (0.028) | | (0.033) |
| Rating A | | | | | | −0.047** | | −0.002 | −0.032 | | 0.011 |
| | | | | | | (0.019) | | (0.052) | (0.020) | | (0.054) |
| Rating BBB | | | | | | −0.010 | | −0.004 | −0.001 | | 0.024 |
| | | | | | | (0.032) | | (0.066) | (0.031) | | (0.071) |
| Group Financials | | | | | | | −0.057*** | −0.056 | | −0.039* | −0.052 |
| | | | | | | | (0.018) | (0.049) | | (0.021) | (0.050) |
| Group Utilities | | | | | | | −0.003 | −0.006 | | −0.005 | −0.027 |
| | | | | | | | (0.023) | (0.058) | | (0.023) | (0.062) |
| Observations | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| $R^2$ | 0.027 | | 0.0001 | | 0.293 | 0.301 | 0.332 | 0.419 | 0.416 | 0.399 | 0.461 |
| Adjusted $R^2$ | -0.015 | | -0.043 | | 0.228 | 0.202 | 0.271 | 0.266 | 0.263 | 0.278 | 0.240 |
| Log Likelihood | | 45.322 | | 45.267 | | | | | | | |
| Akaike Inf. Crit. | | -82.644 | | -82.534 | | | | | | | |
| Bayesian Inf. Crit. | | -77.769 | | -77.659 | | | | | | | |
| Residual Std. Error | 0.047 | | 0.047 | | 0.041 | 0.041 | 0.040 | 0.040 | 0.040 | 0.039 | 0.040 |
| F Statistic | 0.638 | | 0.001 | | 4.551** | 3.021* | 5.470** | 2.738* | 2.709* | 3.315** | 2.081 |
| | (df = 1; 23) | | (df = 1; 23) | | (df = 2; 22) | (df = 3; 21) | (df = 2; 22) | (df = 5; 19) | (df = 5; 19) | (df = 4; 20) | (df = 7; 17) |

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

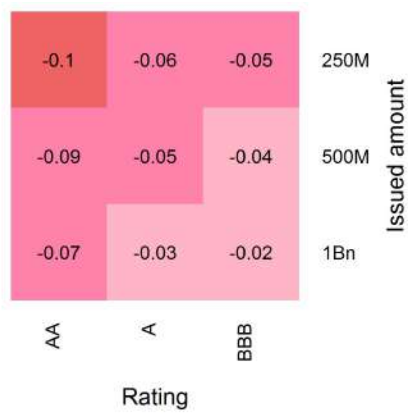
Table 6 – **Results of step 2 regression in the case of EUR bonds.** This table gives the results of step 2 in the OLS and GLS regressions on EUR bonds, where the green bond premium is explained by the characteristics of the bonds. Eleven regressions are performed (nine OLS and two GLS regressions) to explain $\widehat{p}_i(\Delta BA)$. The yield 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 30, 2016. The issued amount is the amount of green bonds issued expressed in USD billions. Issued amount$^2$ is the square of the Issued amount. Group is a qualitative variable, the three modalities of which are Government (reference modality), Financials and Utilities.

| | *Dependent variable:* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\widehat{p}_i^{FEGLS}$(BA) | | | | | | | | | |
| | *OLS* | *OLS* | *OLS* | *OLS* | *OLS* | *GLS* | *OLS* | *OLS* | *OLS* | *OLS* |
| | (p) | (q) | (r) | (s) | (t) | (t) | (u) | (v) | (w) | (x) |
| Constant | 0.072 | −0.002 | −0.068 | −0.019 | −0.007 | −0.006 | 0.060 | 0.135* | −0.019 | 0.076 |
| | (0.051) | (0.054) | (0.056) | (0.033) | (0.027) | (0.027) | (0.050) | (0.068) | (0.030) | (0.078) |
| Yield (%) | −0.065** | | | | | | −0.043 | −0.110** | | −0.067 |
| | (0.024) | | | | | | (0.027) | (0.043) | | (0.051) |
| Maturity (years) | | −0.017 | | | | | | | | |
| | | (0.016) | | | | | | | | |
| Issued amount (bn USD) | | | 0.026 | | | | | | | |
| | | | (0.078) | | | | | | | |
| Rating AA | | | | 0.045 | | | | 0.103 | 0.045 | 0.081 |
| | | | | (0.094) | | | | (0.088) | (0.084) | (0.087) |
| Rating A | | | | −0.083 | | | | −0.024 | 0.274* | 0.191 |
| | | | | (0.058) | | | | (0.057) | (0.145) | (0.156) |
| Rating BBB | | | | −0.111 | | | | 0.160 | 0.127 | 0.214 |
| | | | | (0.079) | | | | (0.129) | (0.115) | (0.130) |
| Group Financials | | | | | −0.128** | −0.130*** | −0.087 | | −0.357** | −0.237 |
| | | | | | (0.047) | (0.047) | (0.052) | | (0.136) | (0.161) |
| Observations | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| $R^2$ | 0.231 | 0.041 | 0.005 | 0.155 | 0.238 | | 0.313 | 0.352 | 0.364 | 0.416 |
| Adjusted $R^2$ | 0.198 | 0.001 | -0.037 | 0.040 | 0.207 | | 0.253 | 0.229 | 0.243 | 0.269 |
| Log Likelihood | | | | | | 20.775 | | | | |
| Akaike Inf. Crit. | | | | | | -33.551 | | | | |
| Bayesian Inf. Crit. | | | | | | -28.518 | | | | |
| Residual Std. Error | 0.114 | 0.127 | 0.130 | 0.125 | 0.113 | | 0.110 | 0.112 | 0.111 | 0.109 |
| F Statistic | 7.189** | 1.017 | 0.111 | 1.343 | 7.512** | | 5.234** | 2.855** | 3.009** | 2.844** |
| | (df = 1; 24) | (df = 1; 24) | (df = 1; 24) | (df = 3; 22) | (df = 1; 24) | | (df = 2; 23) | (df = 4; 21) | (df = 4; 21) | (df = 5; 20) |
| *Note:* | | | | | | | | | | *p<0.1; **p<0.05; ***p<0.01 |

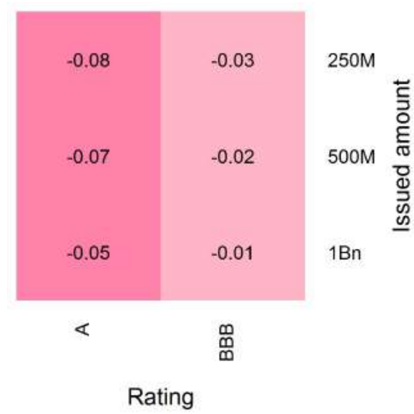
Table 7 – **Results of step 2 regression in the case of USD bonds.** This table gives the results of step 2 in the OLS and GLS regressions performed on USD bonds, where the green bond premium is explained by the characteristics of the bonds. Ten regressions are performed (eight OLS and one GLS regressions) to explain $\widehat{p}_i(\Delta\text{BA})$. The yield 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 30, 2016. The issued amount is the amount of green bonds issued expressed in USD billions. Group is a qualitative variable, the two modalities of which are Financials (reference modality) and Government.



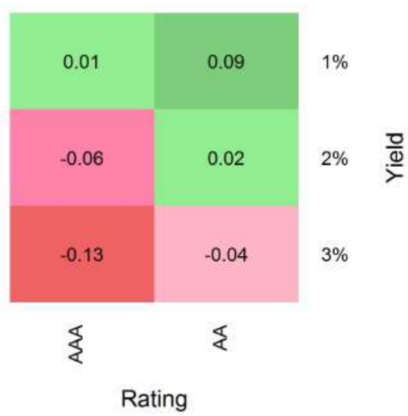

(a) EUR Government-related



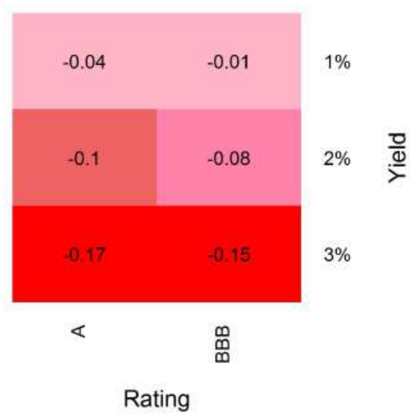

(b) EUR Financials




(c) EUR Utilities




(d) USD Government-related




(e) USD Financials

Figure 2 – **Heatmaps of the green bond premia.** This figure presents three heatmaps of the green bond premia. The three heatmaps of EUR bonds is based on regression (o) and depends on the rating, the issued amount and the group to which the green bond belongs. The two heatmaps of USD bonds are based on regression (x) and depend on the rating, the yield and the group to which the green bond belongs. Negative green bond premia are highlighted with shades of red and positive premia with shades of green. For example, a AA Government-related EUR green bond with an issued amount of USD 500 million carries a -4 basis points green bond premium.

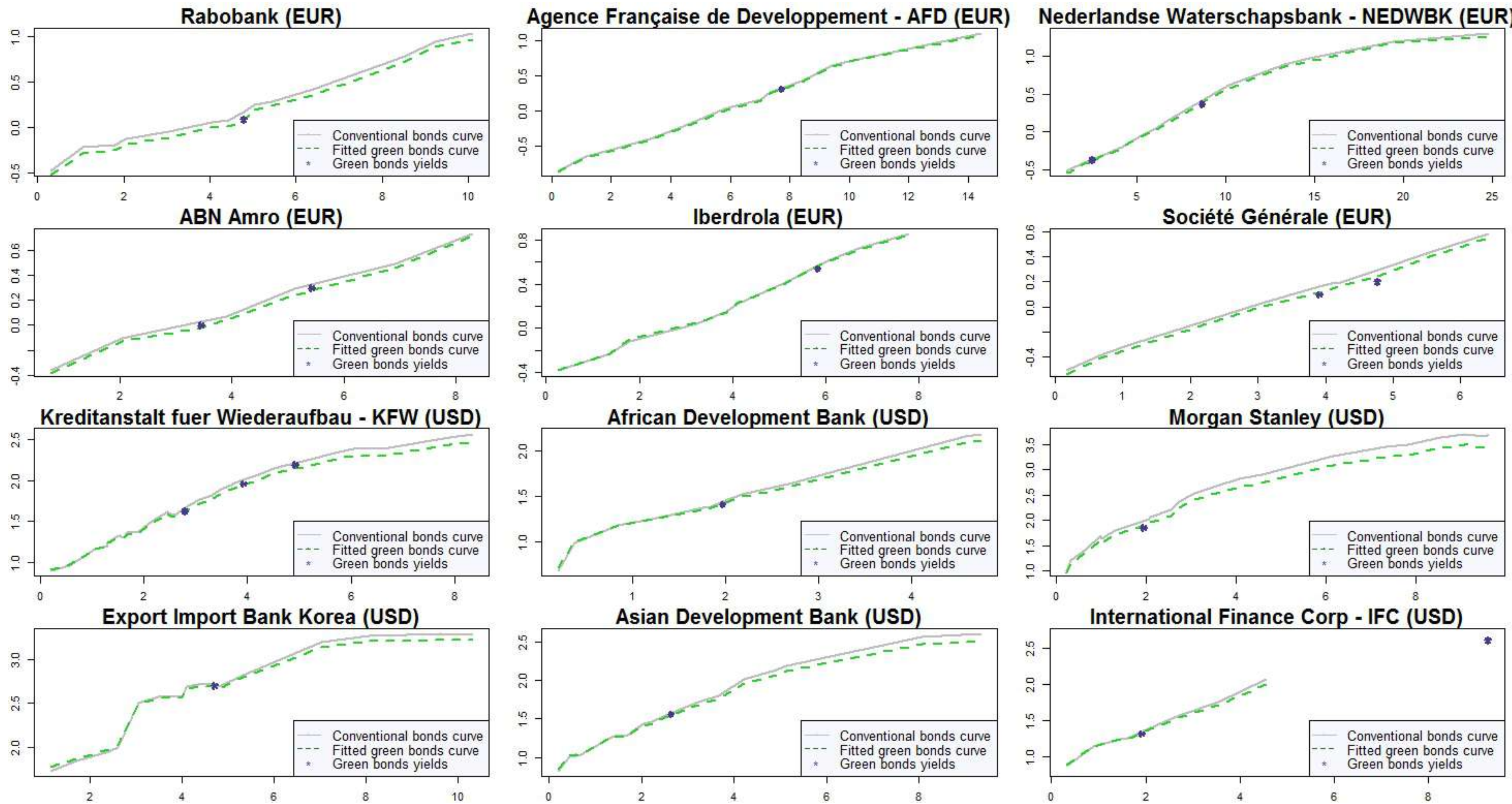
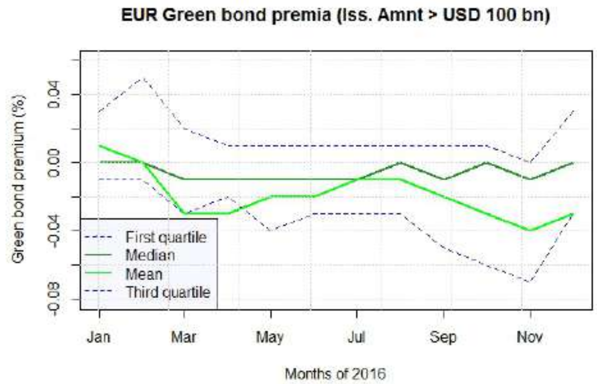
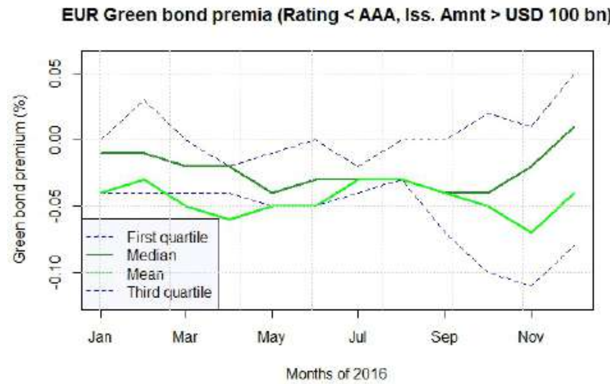


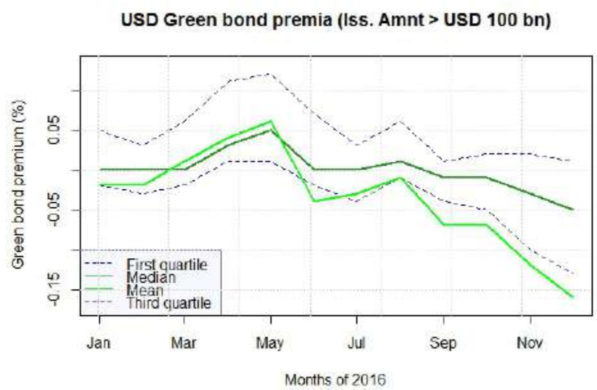

Figure 3 – **The green bond curves.** This figure presents twelve green bond curves (green dashed lines) reconstituted from conventional bond curves (grey solid lines) based on the parameters estimated in step 2 of regressions (o) performed on EUR bonds and (x) performed on USD bonds. The real green bond yields are also shown (blue stars).



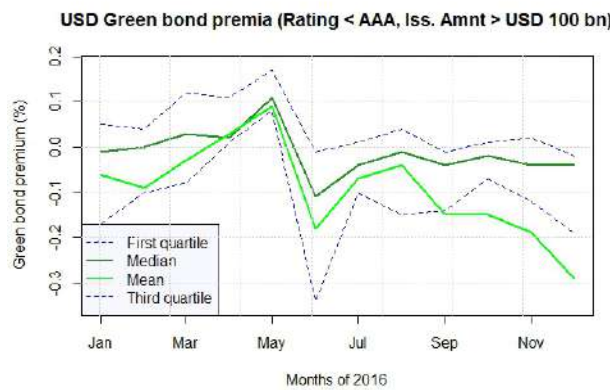

(a) EUR Green bond premia (Iss. Amnt > USD 100 bn)




(b) EUR Green bond premia (Rating < AAA and Iss. Amnt > USD 100 bn)




(c) USD Green bond premia (Iss. Amnt > USD 100 bn)




(d) USD Green bond premia (Rating < AAA and Iss. Amnt > USD 100 bn)

Figure 4 – **Green bond premia dynamics.** This figure shows the evolution with time of the mean (neon green solid line), the median (dark green solid line) and the quartiles (dashed blue lines) of the green bond premium during the year 2016, based on step 1 regression for EUR and USD bonds. We focus in particularly here on issuance levels above USD 100 million and on the subsample of bonds with a rating below AAA. We observe that the mean and median premia were almost always negative during the year 2016.

# Appendix

| | Average green bond yield | | | | |
|---|---|---|---|---|---|
| | **AAA** | **AA** | **A** | **BBB** | **Average** |
| AUD | 2.73 | 2.99 | 3.06 | | 2.90 |
| BRL | 10.88 | | 11.72 | | 11.18 |
| CAD | 1.23 | | | | 1.23 |
| CHF | 0.14 | | | | 0.14 |
| CNY | | | 3.39 | | 3.39 |
| EUR | 0.18 | 0.79 | 0.44 | 0.97 | 0.39 |
| GBP | 0.78 | | | | 0.78 |
| IDR | 8.29 | | | | 8.29 |
| INR | 6.37 | | 7.54 | | 6.76 |
| JPY | | | 0.21 | | 0.21 |
| MXN | 5.51 | | 5.57 | | 5.55 |
| NOK | 1.97 | | | | 1.97 |
| NZD | | | 2.70 | | 2.70 |
| RUB | 8.31 | | | | 8.31 |
| SEK | - 0.07 | | 0.76 | | 0.21 |
| TRY | 10.01 | | | | 10.01 |
| USD | 1.38 | 1.94 | 1.97 | 3.88 | 1.86 |
| ZAR | 7.85 | | | | 7.85 |
| Average | 4.73 | 2.06 | 4.05 | 2.72 | 4.30 |

Table 8 – **Average yield broken down by rating and currency**. This table shows each green bond's average yield with time, depending on the rating and the currency of emission. The average European green bond yields are much lower than those of emerging countries such as Brazil or Turkey.

| **ID** | **Currency** |
|---|---|
| AUD | Australian Dollar |
| BRL | Brazilian Real |
| CAD | Canadian Dollar |
| CHF | Swiss Franc |
| CNY | Chinese Yuan |
| EUR | Euro |
| GBP | Great British Pound |
| IDR | Indonesian Rupiah |
| INR | Indian Rupee |
| JPY | Japonese Yen |
| MXN | Mexican Pesos |
| NOK | Norwegian Krone |
| NZD | New Zeland Dollar |
| RUB | Russian Ruble |
| SEK | Swedish Krone |
| TRY | Turkish Lira |
| USD | US Dollar |
| ZAR | South African Rand |

Table 9 – **Meaning of the currency acronyms**. This table gives the currencies and their acronym.

| | Average issued amounts (in USD) | | |
|---|---|---|---|
| | **Green bond** | **Conventional bond 1** | **Conventional bond 2** |
| AUD | 169 436 053 | 258 406 800 | 249 282 673 |
| BRL | 22 779 244 | 18 080 183 | 16 277 192 |
| CAD | 372 050 000 | 1 041 740 000 | 892 920 000 |
| CHF | 343 525 000 | 269 912 500 | 588 900 000 |
| CNY | 215 820 000 | 143 880 000 | 71 940 000 |
| EUR | 914 170 000 | 1 782 227 000 | 1 817 297 150 |
| GBP | 1 419 100 000 | 4 858 875 000 | 1 635 050 000 |
| IDR | 14 188 686 | 13 500 429 | 10 101 497 |
| INR | 16 165 664 | 14 204 666 | 23 349 204 |
| JPY | 89 846 064 | 120 940 050 | 215 478 417 |
| MXN | 14 279 040 | 8 244 216 | 21 929 904 |
| NOK | 173 550 000 | 173 550 000 | 173 550 000 |
| NZD | 24 962 400 | 24 962 400 | 6 934 000 |
| RUB | 5 010 417 | 17 333 333 | 12 772 500 |
| SEK | 210 526 667 | 184 897 333 | 144 622 667 |
| TRY | 23 394 580 | 10 897 920 | 20 594 420 |
| USD | 577 375 862 | 1 135 917 241 | 1 225 641 379 |
| ZAR | 86 718 562 | 125 547 225 | 279 297 088 |
| Average | 260 716 569 | 566 839 794 | 411 441 005 |
| Median | 129 641 059 | 134 713 613 | 159 086 333 |

Table 10 – **Issued amounts broken down per type of bond and currency**. This table gives the average amount of green bonds issued, CB1 and CB2, in each currency. It shows that the average amounts of green bonds and non-green bonds issued are fairly similar, which suggests the existence of fairly similar levels of liquidity.

| | Dependent variable: | | | | | |
|---|---|---|---|---|---|---|
| | $\widehat{p}_i^{FEGLS}$(BA) | | | | | |
| | (a) | (b) | (c) | (d) | (e) | (f) |
| Constant | 0.082 | 0.017 | 0.010 | 0.030 | 0.024 | 0.030 |
| | (0.058) | (0.016) | (0.017) | (0.025) | (0.024) | (0.032) |
| Yield (%) | −0.040** | −0.017** | −0.014 | −0.018** | −0.018** | −0.017* |
| | (0.019) | (0.008) | (0.009) | (0.008) | (0.008) | (0.009) |
| Maturity (years) | | | | −0.003 | | −0.003 |
| | | | | (0.004) | | (0.004) |
| Issued amount (bn USD) | | | | | −0.008 | −0.007 |
| | | | | | (0.020) | (0.020) |
| Rating AA | | | 0.036 | | | 0.042 |
| | | | (0.041) | | | (0.043) |
| Rating A | | | 0.063 | | | 0.063 |
| | | | (0.055) | | | (0.056) |
| Rating BBB | | | 0.015 | | | 0.020 |
| | | | (0.059) | | | (0.061) |
| Group Financials | −0.062** | −0.072*** | −0.124** | −0.073*** | −0.074*** | −0.127** |
| | (0.026) | (0.022) | (0.051) | (0.022) | (0.022) | (0.051) |
| Group Utilities | 0.016 | −0.003 | −0.037 | −0.0003 | −0.001 | −0.035 |
| | (0.050) | (0.043) | (0.065) | (0.043) | (0.044) | (0.066) |
| Currency CAD | −0.042 | | | | | |
| | (0.074) | | | | | |
| Currency CHF | −0.078 | | | | | |
| | (0.102) | | | | | |
| Currency CNY | 0.088 | | | | | |
| | (0.094) | | | | | |
| Currency EUR | −0.066 | | | | | |
| | (0.059) | | | | | |
| Currency GBP | −0.046 | | | | | |
| | (0.077) | | | | | |
| Currency JPY | −0.029 | | | | | |
| | (0.106) | | | | | |
| Currency NOK | 0.016 | | | | | |
| | (0.094) | | | | | |
| Currency SEK | −0.036 | | | | | |
| | (0.075) | | | | | |
| Currency USD | −0.036 | | | | | |
| | (0.041) | | | | | |
| Currency ZAR | 0.184 | | | | | |
| | (0.134) | | | | | |
| Observations | 69 | 69 | 69 | 69 | 69 | 69 |
| $R^2$ | 0.290 | 0.231 | 0.252 | 0.237 | 0.233 | 0.260 |
| Adjusted $R^2$ | 0.122 | 0.196 | 0.180 | 0.190 | 0.185 | 0.161 |
| Residual Std. Error | 0.086 (df = 55) | 0.082 (df = 65) | 0.083 (df = 62) | 0.083 (df = 64) | 0.083 (df = 64) | 0.084 (df = 60) |
| F Statistic | 1.730* (df = 13; 55) | 6.514*** (df = 3; 65) | 3.488*** (df = 6; 62) | 4.975*** (df = 4; 64) | 4.862*** (df = 4; 64) | 2.635** (df = 8; 60) |

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

Table 11 – **Results of step 2 regressions performed on the whole sample.** This table gives the results of step 2 in the OLS and GLS regressions performed on the whole sample of bonds, where the green bond premium is explained by the characteristics of the bonds. Six OLS regressions are performed to explain $\widehat{p}_i(\Delta BA)$. The yield 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 30, 2016. The issued amount is the amount of green bonds issued expressed in USD billions. Group is a qualitative variable, the three modalities of which are Government (reference modality), Financials and Utilities. Currency is also a qualitative variable standing for the currency of issuance. Table 9 gives the correspondence between the currency and its acronym.

| | *Dependent variable:* | | |
|---|---|---|---|
| | $\widehat{p}_i^{FEGLS}$(BA) | | |
| | (b)+ΔVol (All bonds) | (o)+ΔVol (EUR) | (x)+ΔVol (USD) |
| Constant | 0.016 | −0.031 | 0.066 |
| | (0.016) | (0.039) | (0.082) |
| Yield (%) | −0.017** | | −0.061 |
| | (0.008) | | (0.054) |
| Rating AA | | −0.030 | 0.075 |
| | | (0.034) | (0.089) |
| Rating A | | 0.011 | 0.199 |
| | | (0.056) | (0.160) |
| Rating BBB | | 0.028 | 0.204 |
| | | (0.078) | (0.135) |
| Issued amount | | 0.051 | |
| | | (0.054) | |
| Issued amount$^2$ | | −0.011 | |
| | | (0.016) | |
| Group Financials | −0.070*** | −0.052 | −0.242 |
| | (0.022) | (0.051) | (0.165) |
| Group Utilities | −0.010 | −0.028 | |
| | (0.044) | (0.064) | |
| ΔVolatility | −0.639 | 0.118 | −0.858 |
| | (0.890) | (0.782) | (1.901) |
| Observations | 69 | 25 | 26 |
| $R^2$ | 0.237 | 0.462 | 0.422 |
| Adjusted $R^2$ | 0.190 | 0.193 | 0.239 |
| Residual Std. Error | 0.083 (df = 64) | 0.042 (df = 16) | 0.111 (df = 19) |
| F Statistic | 4.978*** (df = 4; 64) | 1.719 (df = 8; 16) | 2.310* (df = 6; 19) |
| *Note:* | | | *p<0.1; **p<0.05; ***p<0.01 |

Table 12 – **Test of the significance of ΔVolatility.** This table shows the effect of adding a variable of difference in risk (ΔVolatility.) to specifications (b), (o) and (x). It emerges from the three regressions that this variable does not have any significant effects.

| | Dependent variable: $\widehat{p}_i^{FEGLS}$(BA) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. 16 | Feb. 16 | Mar. 16 | Apr. 16 | May 16 | Jun. 16 | Jul. 16 | Aug. 16 | Sep. 16 | Oct. 16 | Nov. 16 | Dec. 16 |
| Constant | −0.083 | −0.045 | 0.015 | 0.0002 | −0.022 | −0.045 | −0.031 | −0.039 | −0.025 | −0.017 | −0.006 | 0.043 |
| | (0.147) | (0.110) | (0.108) | (0.078) | (0.060) | (0.061) | (0.060) | (0.049) | (0.041) | (0.055) | (0.091) | (0.142) |
| Issued amount (bn USD) | 0.203 | 0.120 | −0.024 | 0.007 | 0.038 | 0.091 | 0.061 | 0.070 | 0.018 | 0.010 | −0.025 | −0.120 |
| | (0.185) | (0.139) | (0.135) | (0.097) | (0.080) | (0.081) | (0.080) | (0.066) | (0.054) | (0.074) | (0.126) | (0.189) |
| Issued amount$^2$ | −0.057 | −0.033 | 0.009 | 0.0001 | −0.008 | −0.024 | −0.015 | −0.018 | −0.002 | 0.0004 | 0.010 | 0.038 |
| | (0.051) | (0.038) | (0.037) | (0.027) | (0.023) | (0.024) | (0.023) | (0.019) | (0.016) | (0.021) | (0.037) | (0.054) |
| Rating AA | −0.121 | −0.082 | −0.027 | −0.045 | −0.047 | −0.063 | −0.042 | −0.052 | −0.050 | −0.058 | −0.038 | 0.006 |
| | (0.122) | (0.091) | (0.089) | (0.060) | (0.049) | (0.051) | (0.050) | (0.041) | (0.033) | (0.046) | (0.079) | (0.117) |
| Rating A | −0.081 | −0.076 | −0.044 | −0.062 | −0.047 | −0.062 | −0.051 | −0.033 | 0.008 | −0.077 | −0.133 | 0.017 |
| | (0.093) | (0.070) | (0.069) | (0.055) | (0.048) | (0.049) | (0.048) | (0.040) | (0.032) | (0.075) | (0.132) | (0.191) |
| Rating BBB | −0.052 | −0.042 | −0.022 | −0.024 | −0.037 | −0.041 | −0.034 | −0.032 | 0.040 | −0.072 | −0.162 | 0.037 |
| | (0.125) | (0.094) | (0.092) | (0.074) | (0.063) | (0.065) | (0.064) | (0.052) | (0.033) | (0.098) | (0.173) | (0.252) |
| Group Financials | 0.035 | 0.064 | −0.012 | −0.011 | 0.004 | 0.043 | 0.042 | 0.026 | −0.047 | 0.004 | −0.008 | −0.100 |
| | (0.137) | (0.103) | (0.096) | (0.074) | (0.061) | (0.062) | (0.061) | (0.050) | (0.042) | (0.067) | (0.120) | (0.172) |
| Group Utilities | | | | | | | | | | 0.123 | 0.245 | 0.085 |
| | | | | | | | | | | (0.085) | (0.151) | (0.217) |
| Observations | 15 | 15 | 16 | 17 | 19 | 19 | 19 | 19 | 21 | 23 | 24 | 24 |
| $R^2$ | 0.324 | 0.237 | 0.146 | 0.311 | 0.271 | 0.308 | 0.191 | 0.290 | 0.460 | 0.533 | 0.493 | 0.215 |
| Adjusted $R^2$ | -0.184 | -0.336 | -0.424 | -0.102 | -0.094 | -0.037 | -0.214 | -0.065 | 0.228 | 0.315 | 0.271 | -0.128 |
| Residual Std. Error | 0.112 | 0.084 | 0.083 | 0.067 | 0.059 | 0.060 | 0.059 | 0.048 | 0.040 | 0.055 | 0.098 | 0.140 |
| F Statistic | 0.638 | 0.413 | 0.256 | 0.753 | 0.742 | 0.892 | 0.471 | 0.818 | 1.984 | 2.442* | 2.222* | 0.628 |
| | (df = 6; 8) | (df = 6; 8) | 0.256 | 0.753 | 0.742 | 0.892 | 0.471 | 0.818 | 1.984 | 2.442* | 2.222* | 0.628 |

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

Table 13 – **Results of step 2 regression (o) on a monthly basis in the case of EUR bonds.** This table gives the results of specification (o) for EUR bonds on a monthly basis for the whole year 2016. The green bond premium, $\widehat{p}_i(\Delta\text{BA})$, is explained by the characteristics of the bonds. 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 30, 2016. The issued amount is the amount of green bonds issued expressed in USD billions. Issued amount $^2$ is the square of the Issued amount. Group is a qualitative variable, the three modalities of which are Government (reference modality), Financials and Utilities.

| | *Dependent variable:* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\widehat{p}_i^{FEGLS}$(BA) | | | | | | | | | | | |
| | Jan. 16 | Feb. 16 | Mar. 16 | Apr. 16 | May 16 | Jun. 16 | Jul. 16 | Aug. 16 | Sep. 16 | Oct. 16 | Nov. 16 | Dec. 16 |
| Constant | 0.122 | 0.030 | 0.092 | 0.168 | 0.146* | 0.196 | 0.163** | 0.129** | 0.085 | 0.151 | 0.079 | −0.169 |
| | (0.154) | (0.179) | (0.213) | (0.103) | (0.066) | (0.118) | (0.067) | (0.056) | (0.222) | (0.207) | (0.287) | (0.391) |
| Yield (%) | −0.077 | 0.0002 | −0.045 | −0.088 | −0.081 | −0.117 | −0.105** | −0.079* | −0.044 | −0.113 | −0.089 | 0.094 |
| | (0.110) | (0.132) | (0.157) | (0.078) | (0.050) | (0.086) | (0.048) | (0.040) | (0.161) | (0.142) | (0.189) | (0.257) |
| Rating AA | | | | | | | 0.081 | | 0.003 | 0.099 | 0.143 | 0.00001 |
| | | | | | | | (0.102) | | (0.339) | (0.309) | (0.321) | (0.437) |
| Rating A | 0.347 | −0.243 | 0.019 | 0.221 | 0.169 | −0.176 | 0.039 | 0.210* | −0.110 | −0.094 | 0.079 | 0.181 |
| | (0.198) | (0.236) | (0.281) | (0.140) | (0.094) | (0.240) | (0.126) | (0.105) | (0.423) | (0.400) | (0.577) | (0.785) |
| Rating BBB | 0.140 | 0.005 | 0.117 | 0.184 | 0.157 | 0.207 | 0.216* | 0.180* | 0.122 | 0.254 | 0.326 | 0.109 |
| | (0.203) | (0.244) | (0.286) | (0.146) | (0.095) | (0.200) | (0.116) | (0.095) | (0.386) | (0.346) | (0.483) | (0.657) |
| Group Financials | −0.297 | 0.044 | −0.068 | −0.143 | 0.035 | −0.102 | −0.075 | −0.171 | −0.121 | −0.047 | −0.282 | −0.662 |
| | (0.199) | (0.239) | (0.275) | (0.142) | (0.092) | (0.238) | (0.137) | (0.113) | (0.459) | (0.423) | (0.596) | (0.812) |
| Observations | 11 | 12 | 11 | 13 | 13 | 14 | 20 | 17 | 21 | 24 | 26 | 26 |
| $R^2$ | 0.545 | 0.383 | 0.088 | 0.402 | 0.659 | 0.621 | 0.570 | 0.680 | 0.201 | 0.176 | 0.138 | 0.159 |
| Adjusted $R^2$ | 0.241 | 0.031 | -0.520 | 0.103 | 0.489 | 0.453 | 0.416 | 0.574 | -0.066 | -0.053 | -0.078 | -0.051 |
| Residual Std. Error | 0.124 | 0.149 | 0.170 | 0.088 | 0.057 | 0.148 | 0.087 | 0.072 | 0.292 | 0.277 | 0.403 | 0.549 |
| F Statistic | 1.794 | 1.088 | 0.145 | 1.345 | 3.867** | 3.688** | 3.711** | 6.389*** | 0.753 | 0.767 | 0.640 | 0.756 |
| | (df = 4; 6) | (df = 4; 7) | (df = 4; 6) | (df = 4; 8) | (df = 4; 8) | (df = 4; 9) | (df = 5; 14) | (df = 4; 12) | (df = 5; 15) | (df = 5; 18) | (df = 5; 20) | (df = 5; 20) |

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

Table 14 – **Results of step 2 regression (x) on a monthly basis in the case of USD bonds.** This table gives the results of specification (x) for USD bonds on a monthly basis for the whole year 2016. The green bond premium, $\widehat{p}_i(\Delta \text{BA})$, is explained by the characteristics of the bonds. The yield is expressed in percentage. The rating is a qualitative variable, the four modalities of which are AAA (reference modality), AA, A and BBB. Group is a qualitative variable, the two modalities of which are Government (reference modality) and Financials.

| Maturity of CB1 < 1 year: | Average $\widehat{p}_i^{FEGLS}(\Delta\text{BA})$ (in %) | Significantly different from zero |
|---|---|---|
| EUR bonds > USD 100m | -0.02 | Yes at 90% |
| EUR bonds > USD 100m: AA + A + BBB | -0.04 | Yes at 99% |
| USD bonds > USD 100m | -0.04 | Yes at 90% |
| USD bonds > USD 100m: AA + A + BBB | -0.07 | Yes at 83% |

Table 15 – **Green bond premia in several market segments (sample with CB1$<$ 1 year).** This table shows, in the case of green bonds with which the closest conventional bond's maturity is less than one year, the average green bond premium in several market segments and the level of significance at which $H_0 : \text{Mean}(\widehat{p}_i) = 0$ is rejected. We focus here on 4 market segments and observe that the results are very similar to those presented in Table 5

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