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, The Imperative of Responsibiliy, *The University of Chicago Press*, 1984.

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, i.e. one fifth of the global universe. The average green bond premium is found to be significantly negative from the green bonds' issuance date to December 30, 2016, especially in several segments, such as EUR and USD bonds where the issued amount is greater than USD 100 million (-2 bps and -5 bps, respectively) and particularly in the subsamples of below-AAA EUR and USD bonds (-4 bps and -9 bps, respectively). The rating and the issued amount are the main drivers of green bond premia in the case of EUR bonds: 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 yield and is substantially lower with Financials than Government-related bonds, although the positive effects of a lower rating counterbalance this trend. We conclude that regulatory and fiscal measures are required to keep on feeding the pipeline of green bonds issued and creating incentives for investing in green debt.

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[*] Université de Lyon, Université Lyon 1, Institut de Sciences Financière et d'Assurances, 50 avenue Tony Garnier, F-69007 Lyon, France and Groupama Asset Management, 25 rue de la Ville-l'Evêque, 75008 Paris, France. I am grateful to Jean-François Boulier, Marc Boubal, Ian Cochran, Christian Francq, Christian Gouriéroux, Olivier Guéant, Nabil Kazi-Tani, Morgane Nicol, Joël Petey, Xavier Pieri, Bacem Rezgui, Christian Robert, Igor Shishlov as well as the participants of the CREST Financial Econometric Seminar and the ACDD Conference for their helpful comments and suggestions. The paper reflects the author's opinions and not necessarily those of Groupama Asset Management.

1 Introduction

One of the great innovations made 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)). Institutional investors, including banks, hold more than 80% of the institutional assets under management in middle-income countries (McKinsey (2016)). Private investors therefore have the resources required to drive and amplify the environmental transition by supplementing public funding and complementing the current regulation[2]. 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)).

While banks are not particularly 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

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[1] Institutional investors include pension funds, insurance companies and sovereign wealth funds.

[2] For more than twenty years, governments and international institutions have addressed the peril of environmental damage via environmental regulations and public investments in order to spearhead the correction of negative externalities. However, the main concern is that there is little public financial support for the magnitude of the required efforts. In Europe, for example, although the cost of producing renewable energy has kept on decreasing, the latest financial crisis resulted in a considerable drop in public investment in the new forms of energy. In addition, due to the decrease in the post-crisis GDP along with governments' reluctance to tighten the regulation of carbon credits, the carbon price dropped dramatically to EUR 5 in early 2017.

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.

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)), and 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 diversify their assets by moving towards sustainable investment projects. The Green Bond Principles[3] are "voluntary process guidelines that recommend transparency and disclosure, and promote integrity in the development of the Green Bond market" (ICMA (2016)). 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[4]. Green bonds are therefore one of the most practical and effective levers to strenghten and

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[3] 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.

[4] 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 debt securities issued in 2013 actually amounted to around USD 100 trillion (Bank for International Settlements (2014)).

accelerate the funding of the environmnetal transition.

The labelled green bond market reached USD 115 billion outstanding in March 2016 (Climate Bonds Initiative (2016)). These bonds have constantly increased 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[5], the share of corporate and financial[6] 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; 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. However, the green bonds issuance still accounts for only a very small proportion of the total annual bond issuance, which amounts to USD 19 trillion (OECD (2015c)).

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 (Nelson (2014) and Nelson and Pierpont (2013)). Indeed, as the cost of sustainable energy infrastructures[7] is decreasing, the cost of financing becomes the major factor on which the long term cost of electricity depends: the cost of capital amounts to 50% to 70% of the cost of electricity production, while the operational costs of installation account for the balance (Bradford and Hoskins (2013)). However, although some institutional investors compete for acquiring green debt, the prospects of a lower yield may discourage all 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)).

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[5] The European Investment Bank has emitted the largest amount of green bonds (USD 17 billion) and was the leading issuer in 2014 and 2015.

[6] Financial green bonds are securities that enable a bank to fund retail and corporate green projects.

[7] Here we have taken the sustainable energy infrastructure to include the following sectors: solar and wind power production, small hydro plants, geothermal, marine, biomass and biofuel sources, carbon capture and sequestration and energy smart technologies.

This article therefore aims to provide answers to the following questions: Is there a lower yield for investors to finance the environmental transition? Do project holders have the opportunity to issue green bonds at a lower yield than a conventional bond's yield? What are the consequences in terms of market microstructure?

Thus, the main question it is proposed to address here is whether there is a negative premium which is specific to green bonds. In other words, 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 used to calculate the yield of an equivalent synthetic conventional bond for each green bond issued on 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.

As far as we know, this is the first academic study focusing on the specific cost of green bonds. The most original feature of this article 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, we show that there is a negative premium on green bonds yield, which we quantify here and explain on the basis of the characteristics of the bond. 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 (-2 basis points), EUR bonds with a rating lower than AAA (-4 basis points), USD bonds (-5 basis points), and USD bonds with a rating lower than AAA (-9 basis points). Lastly, as a corollary to the second point, we point out that this situation is conducive to more green bond issuance with a primary yield lower than the conventional benchmark. However, at the same time, the desincentive green bond yield tends to concentrate the purchase of green bonds on green investors which increases the systemic risk level and does not accelerate the funding of the environmental transition. Therefore, regulatory and fiscal measures can be implemented in order to keep on increasing the supply of green bonds while concurrently maintaining the incentives for investing in green debt.

This paper is organized as follows. In the second section, the literature on the fields 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 paper 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

Many authors have addressed the effects of Corporate Social Responsibility (CSR), especially those of good environmental performances, on companies' stock prices (Heinkel et al. (2011)) and performances (Konar and Cohen (2001), Derwall et al. (2005), Kempf and Osthoff (2007), Statman and Glushkov (2009), Semenova and Hassel (2008), Dixon (2010)). Although no consensus has been reached so far about the relationship between Corporate Social Performance (CSP) and Corporate Financial Performance (CFP), most of the articles published so far have suggested that the former has a positive impact on the latter. In addition, CSP has been found to have similar effects on the cost of equity capital (ElGhoul et al. (2011), Chava (2010), Sharfman and Fernando (2008) Chava (2014) and Dhaliwal et al. (2011)): firms with better CSPs (ElGhoul et al. (2011)) or a more favorable environmental impact (Chava (2010) and Sharfman and Fernando (2008)) benefit from a lower cost of equity capital.

However, these findings are not necessarily transferable to the debt market for several reasons. Firstly, the payoff profile of a debtholder differs from that of a stockholder (Oikonomou et al. (2014) and Ge and Liu (2015)): Merton (1973) reported that a bond payoff can be replicated by the purchase of a stock and the sale of a call option on the same asset. Since bondholders have little upside available, it is therefore crucial for them to analyze and assess all the downside risks, including environmental hazards. Secondly, the debt market is huge (more than USD 21 trillion outstanding debt on the first quarter of 2016 according to the Bank of International Settlement) and bonds generally account for a larger share of companies' balance sheet than equities. Thirdly, as previously suggested Oikonomou et al. (2014), since firms refinance themselves via the debt market more frequently than they increase their capital, they are more sensitive to the pressure exerted by green investors. This pressure can be all the more easily exerted as debt instruments are frequently held by institutional investors who are able to analyze their investments carefully and do whatever is required to make their voice heard.

As a matter of fact, there are two conflicting schools of thought about the effects of environmental performances on the cost of capital. Advocates of the shareholder theory, which is based on the seminal studies by Friedman (1962) and Friedman (1970), regard environmental expenditure as an inefficient use of resources liable to reduce profits (Kim et al. (2009) and Frooman et al. (2008)) and the ability to pay interests, which subsequently increases the cost of capital and the bond credit spread. The followers of the stakeholder theory allege, however, that good environmental performances decrease the cost of capital via a three-fold process. Firstly they have a positive impact on the company's revenue, which reduces litigation, sanctions and boycott risks and increases customer activities and government support (Thompson and Cowton (2004), Anderson and Sullivan (1993) and Kassinis and Vafeas (2002)). Secondly, it reduces the information asymmetry with the lender and thus prevents adverse selection processes (Heinkel et al. (2011), Hong and Kacperczyk (2009), Jones (1995) and Orlitzky et al. (2003)) and especially environmental hazard risks. Thirdly, good environmental performances increase the size of the bondholder base, which exerts a downward pressure on bond yields (Heinkel et al. (2011) and Ge and Liu (2015)).

Only a 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. The latter authors argue that this happens only if the country's CSR score is above average. By contrast, Bauer and Hann (2010), 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, Frooman et al. (2008) also report that default risk and CSP are inversely related. Comparing CSR to non CSR US corporate debt in an extensive longitudinal data set, Oikonomou et al. (2014) reach similar conclusions, i.e., that good CSR performances are rewarded via a lower yield and CSR irresponsibility is positively correlated with financial risk. Ge and Liu (2015) focus on the effects of CSP disclosure on the spreads of new corporate bonds issued in the US primary market. Although this is not the question addressed here, the conclusion reached by the latter authors is fairly similar to the previous ones since they establish that firms reporting favorable CSPs enjoy lower bond spreads. Lastly, although the financing of private loans and public bonds has to be analyzed differently, mainly because banks have access to more information than bondholders, Goss and Roberts (2011) reach similar conclusions after examining the impact of the CSR scores of 8525 companies on the cost of their bank loans. They also establish that firms with the lowest CSR scores pay up to 20 basis points (bps) more than the most responsible firms.

However, no academic studies on the cost of the "greenness" of bonds have ever been published so far to our knowledge. 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 (2015c) report states that the financial characteristics of green bonds and conventional bonds produced by the same issuer are identical at 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.

The three only existing study that tackle this issue are bank reports (Barclays (2015), Bloomberg (2017) and HSBC (2016)) which focus on a small number of bonds (the Global Credit universe in August 2015, 12 supranational bonds and 30 bonds, respectively), do not control for the difference in liquidity and do not use any particular technique to compare the green bond yields with the conventional bond yiels (except Barclays (2015) that consider an OLS regression of the credit spread on some market risk factors). While the first two studies highlight the existence of a negative green bond premium (-17 bps and -25 bps, respectively), HSBC (2016) claims that the cases of negative and positive premia found cannot point to a systemic negative premium. The issues of the existence and *a fortiori* the determinants of a green bond premium therefore remain open-ended questions that 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 (a linear, panel or time series 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 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, a potential lack of data and the problem of robustness. Lastly, when the sample of bonds is too small or there are only a few observations, as in the case on the emerging green bond market, the quality of the results is bound to be questionable.

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), Strebulaev (2001) 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 yields – especially bond credit spreads – incorporate a liquidity premium: Gomez-Puig (2006), Bao et al. (2011), Dick-Nielsen et al. (2012), Beber et al. (2009) and de Jong and Driessen (2006) describe how the credit spread increases in the case of bonds with a lower liquidity. As a matter of fact, the authors of a study on a large class of structural models, Huang and Huang (2012), observe that the credit risk accounts for only a small fraction (between 20% to 30%) of the yield spreads in the case of investment-grade bonds. As might be expected, Chen et al. (2007), Beber et al. (2009) and Bao et al. (2011) establish that the liquidity is all the lower as the credit rating is low. Van Loon et al. (2015) and de Jong and Driessen (2006) put the same idea differently by showing that a higher liquidity premium accompanies low credit ratings. In terms of the dynamics, Friewald et al. (2012), in a study focusing on the US corporate bond market, establish that the liquidity premium accounts for 14% of change in the credit spread and that this impact is significantly greater during periods of crisis and in the case of speculative grade bonds.

For each green bond in our database, we design a comparable conventional bond and perform panel regressions to assess the green yield cost, controlling the difference in liquidity between the two bonds. 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) Van Loon et al. (2015), 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 (2011)) 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".

To obtain this equivalent synthetic conventional bond, 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. In each case, we search for the two conventional bonds with the closest maturity, from the same issuer, having exactly the same characteristics[8]: 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 an 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. 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 bond's issued amount and greater than one quarter of this amount. 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. 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), an those which are non bullet (4 bonds) or non senior bonds (9 bonds)[9]. We therefore focus on the

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

[9] 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.

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[10] 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[11], 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 our panel. We then interpolate or extrapolate[12] 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 building a key variable: the yield spread between the green bond and the equivalent synthetic conventional bond. Let $y_{i,t}^{GB}$ and $\tilde{y}_{i,t}^{CB}$ be the green bond and the conventional bond i ask yield, respectively, on day t. We take $\Delta\tilde{y}_{i,t} = y_{i,t}^{GB} - \tilde{y}_{i,t}^{CB}$. With a view to filtering the database, we also define $\Delta\%\tilde{y}_{i,t} = \frac{y_{i,t}^{GB} - \tilde{y}_{i,t}^{CB}}{|\tilde{y}_{i,t}^{CB}|}$, which must be regarded as a relative change[13]: this is the amount by which the green bond yield is greater or lower than the equivalent

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

[11] 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.

[12] 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.

[13] Here we divide the difference by the absolute value of $\tilde{y}_{i,t}^{CB}$ so as to keep the partial order when dealing with

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. (2006) 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[14] (see Table 8), constituting the final 43,445-line unbalanced panel to work on. In 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 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 9): 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%.

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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.

[14] See supplementary material for a detailed list.

	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 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.

Upon focusing on the difference in yield, the distribution 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.

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[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 on 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 developed 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 premium on a conventional bond yield can in fact be either positive or negative.

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 11). 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:

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

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 improve the efficiency of the estimation.

This whole procedure enables us to control the liquidity in two ways: first, by constructing $\Delta\tilde{y}_{i,t}$ we limit the differences in liquidity, and secondly, the residual liquidity bias is controlled via the fixed effect regression in order to isolate and estimate the unobserved bonds' specific heterogeneity $\widehat{p_i}$,

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[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.

which is the green bond premium.

4.1.2 Step 2: The determinants of the green premium

In the second step, the determinants of the green bond premium are assessed, 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 η_i to denote the error term, we set:

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

(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.

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

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 Maturity^2 and Issued Amount^2.

In this two-step procedure, we first take the characteristics of each pair of bonds in the Within regression procedure and then extrapolate the green bond premia observed to all the green bonds, based on the characteristics of each bond. When an issuer has emitted only a few green bonds or none, an estimated green bond yield curve can therefore be drawn up from the conventional bond curve of each issuer.

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[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.

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 day-to-day 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[20], 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 or the issue date (or off-the-run versus on-the-run indicators) therefore cannot be used.

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 yield bid-ask spread instead of the price bid-ask spread in order to have homogeneous variables in the regression (3). The zero trading day is a variable that equals 1 if the bond price does not vary during a trading day and zero otherwise. It is worth noting that these two proxies do not reflect the same information about the liquidity: the former expresses the cumulative buying and selling pressure, whereas the latter reflects the scarcity of the trading activity on a bond.

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.

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%

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[20] Dick-Nielsen (2014) has developed a method for cleaning TRACE data and addressing liquidity biases.

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.

The statistics show that the variables are concentrated around zero and a low standard deviation is observed, especially in the case of ΔZTD. 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 ΔBA and ΔZTD, the presence of an unobserved heterogeneous effect is confirmed via an F-test, a Wooldridge test, a Breusch-Pagan test and a Honda test[21]. 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 ΔBA, contrary to that performed on ΔZTD. Both estimators are unbiased and consistent: although it is intuitive that the 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[22]. 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 (see Bartels (2008)).

We also run Breusch-Godfrey, Durbin Watson and Wooldridge tests, all of which indicate the

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

[22] 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).

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 exactly 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. Although the estimated $\widehat{\beta}$ values are almost equal, the standard error of the estimated coefficient is much lower with the FEGLS than with the FE regression. It is worth noting that the sign of $\widehat{\beta}$ differs between the two regressions for two reasons. First, as specified in section 4.2, these two proxies do not capture the same kind of illiquidity. Secondly, in the regression of $\Delta\tilde{y}_{i,t}$ on ΔBA, $\widehat{\beta}$ can be negative in various cases, for example when the illiquidity shock mainly decreases the ask yield of the green bond with a stable conventional bond's bid-ask spread or when it mainly increases the bid yield of the green bond while the conventional bond's bid-ask spread tightens.

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 green bond premia, denoted ($\widehat{p}_i^{FEGLS}$(BA),

	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 (4iv)) 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.

$\widehat{p_i}^{FE}$(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[23] has a lower standard deviation (28%) than the distribution of $\widehat{p_i}$ (59%).

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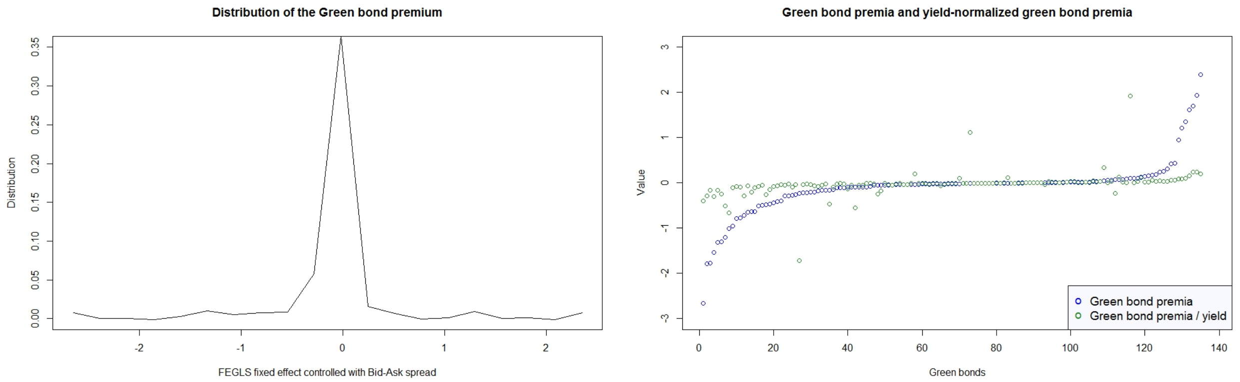
[23] The three bonds with a ratio greater than 100% or lower than -100% have a yield very close to zero.

	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).

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 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.

We thus provide evidence that on average, there exists a negative premium inherent to green bonds. Put differently, in the scope of the present analysis - which accounts for a fifth of all the green bonds issued worldwide - since the date of issuance of the green bonds, the bond holder pays an average premium of 8 bps for the green bond label. Lastly, we test for 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 89% confidence level. This premium is more significantly negative in various market segments. For example, all the EUR-denominated (resp. USD-denominated) bonds with an issued amount of over USD 100 million carry a -2 bps (resp. -5 bps) average premium which differs significantly from zero at a 90% (resp. 95%) confidence level. A further example is that of the EUR-denominated (resp. USD-denominated) bonds with a rating strictly below AAA and an issued amount over USD 100 million having a -4 bps (resp. -9 bps) average green bond premium which differs significantly from zero at a 99% (resp. 90%) confidence level. These results constrast with the ones presentend in Barclays (2015) and Bloomberg (2017) which overestimate the breadth of the negative premium (-17 bps and -25 bps, respectively).

	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 $H_0 : \text{Mean}(\widehat{p}_i) = 0$. 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.

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 on EUR and USD (equation (5)). For the sake of a robust analysis, we exclude bonds and private placements with a very 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[24], giving a total number of 69 green bonds for the regression (4).

We present the regressions for $\widehat{p}_i^{FEGLS}(\mathrm{BA})$ 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 $\widehat{p}_i^{FE}(\mathrm{BA})$, $\widehat{p}_i^{FEGLS}(\mathrm{ZTD})$ and $\widehat{p}_i^{FE}(\mathrm{ZTD})$ because the variables are very similar (see Table 4). We focus specifically on combinations of independent variables that have an effect for each of the three regressions. For example, there is no evidence of a quadratic effect of the maturity, the issued amount or the rating for 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[25] 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 12), whereas the last two regressions (equation (5)) performed on the EUR and the USD subsamples explain 46.1% and 41.6% of the total variance, respectively (see Tables 6 and 7).

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[24] 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. We then compare an OLS regression on the reduced sample with an M-estimator on the sample with the two bonds included, and observe that the estimated parameters are very similar.

[25] See Additional Material for a detailed analysis of the tests performed.

	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 $\widehat{p}_i(\Delta\text{BA})$. 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. 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: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

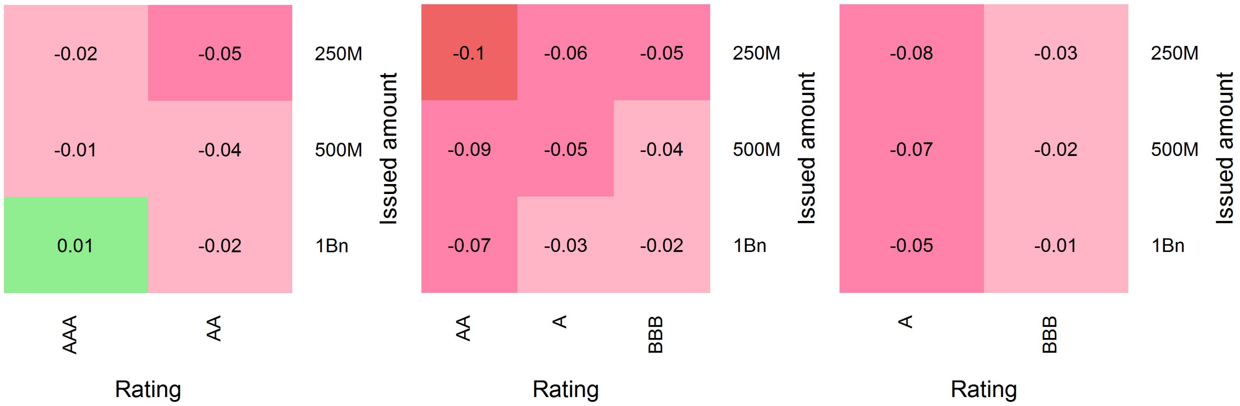
Table 7 – **Results of step 2 regression in the case of USD bonds.** This table gives the results of step 2 in the OLS and GLS regressions performed on USD bonds, where the green bond premium is explained by the characteristics of the bonds. Ten regressions are performed (eight OLS and one GLS regressions) to explain $\widehat{p}_i(\Delta \mathrm{BA})$. 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.

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 determinants of 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 rating, the size of the issuance and the group (see (o)). 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. In addition, 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). Lastly, the USD bond premium 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.

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 are mainly negative in the case of EUR and USD Financial bonds. For example, the yield of a EUR A Utility green bond with an issued amount of USD 500 million is 7 bps lower, for instance, than that of an equivalent conventional bond. Generally speaking, it can be seen from the EUR heatmap that corporate EUR bonds, especially A bonds, with a small issued amount obtain the greatest negative premium (up to -10 bps), contrary to high rated Government-related EUR bonds with a large issued amount (+1 bp). The amplitude of the EUR green premia is not very wide however, mainly because of the low European rate environment resulting from the ECB's Quantative Easing measures combined with low growth and low inflation rates. In the case of USD bonds, the higher the yield or the rating, the lower the premium will be. For example, the yield of a AAA Government-related green bond is 6 bps lower than that of an equivalent conventional bond with a 2% yield, whereas the yield of a A Financial green bond is 10 bps lower than that of an equivalent conventional bond with a 2% yield. The amplitude of USD green premia is wider than that of EUR premia, mainly because of the higher rate environment provided by the Federal Reserve *tapering* combined with the robust growth and high inflation rates.

In the final step, a green bond curve can be obtained from a conventional bond curve by applying the 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 corresponding to twelve different issuers. The quality of the fit obtained 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.



Issued amount	AAA	AA
250M	-0.02	-0.05
500M	-0.01	-0.04
1Bn	0.01	-0.02

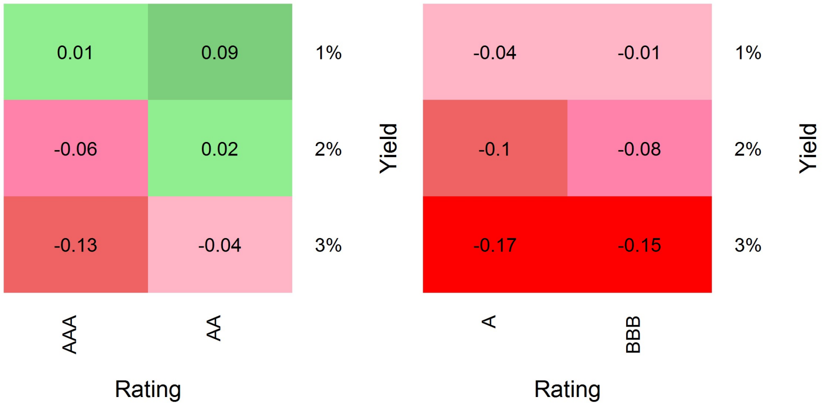
(a) EUR Government-related

Issued amount	AA	A	BBB
250M	-0.1	-0.06	-0.05
500M	-0.09	-0.05	-0.04
1Bn	-0.07	-0.03	-0.02

(b) EUR Financials

Issued amount	A	BBB
250M	-0.08	-0.03
500M	-0.07	-0.02
1Bn	-0.05	-0.01

(c) EUR Utilities



Yield	AAA	AA
1%	0.01	0.09
2%	-0.06	0.02
3%	-0.13	-0.04

(d) USD Government-related

Yield	A	BBB
1%	-0.04	-0.01
2%	-0.1	-0.08
3%	-0.17	-0.15

(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.

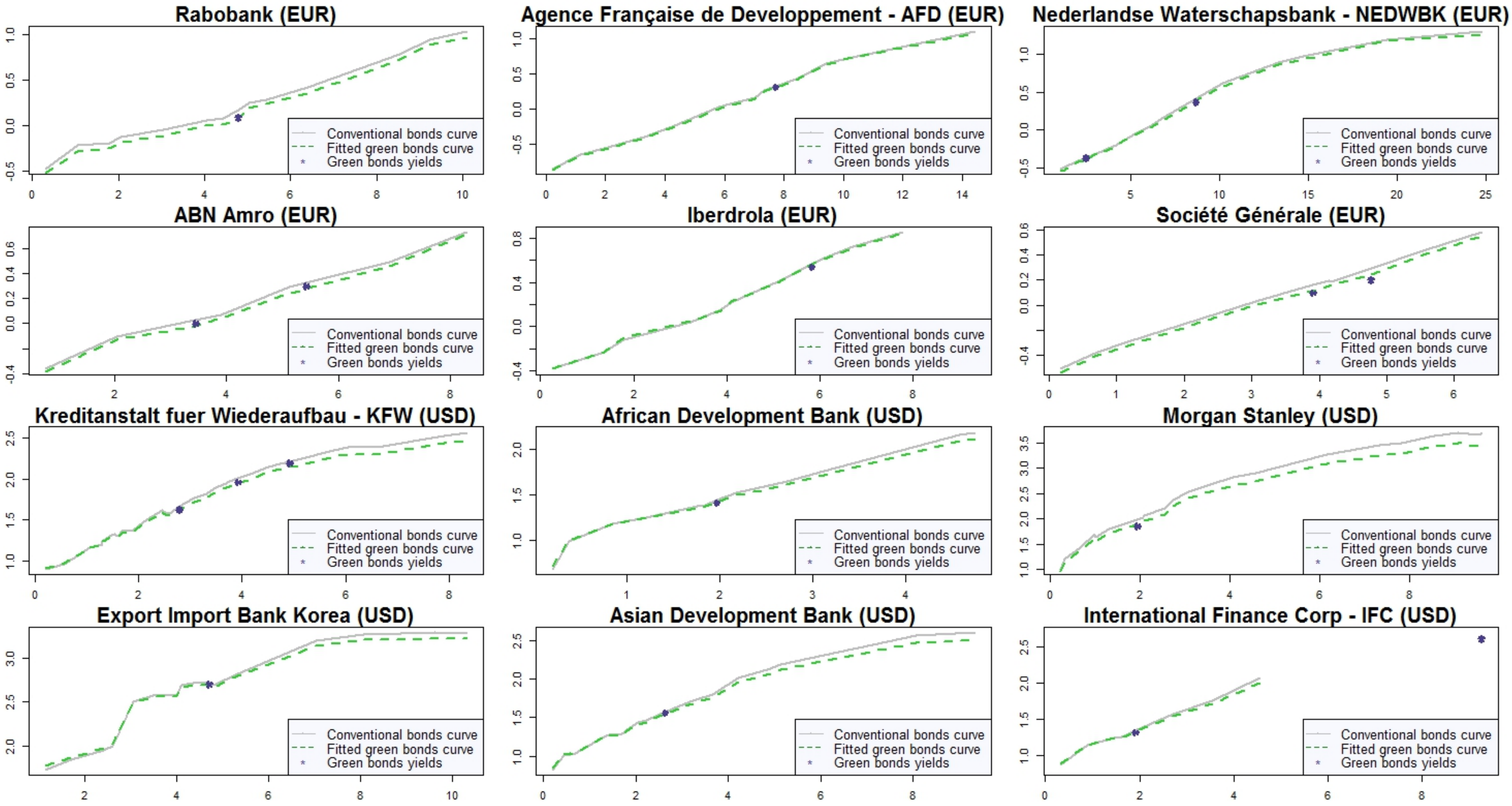


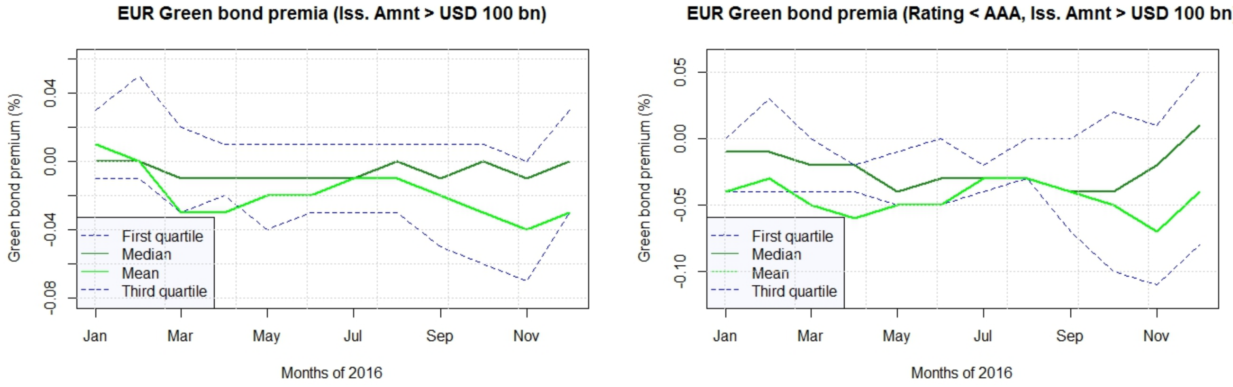
Figure 3 – **The green bond curves.** This figure presents twelve green bond curves (green dashed lines) reconstituted from conventional bond curves (grey solid lines) based on the parameters estimated in step 2 of regressions (o) performed on EUR bonds and (x) performed on USD bonds. The real green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

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 13).

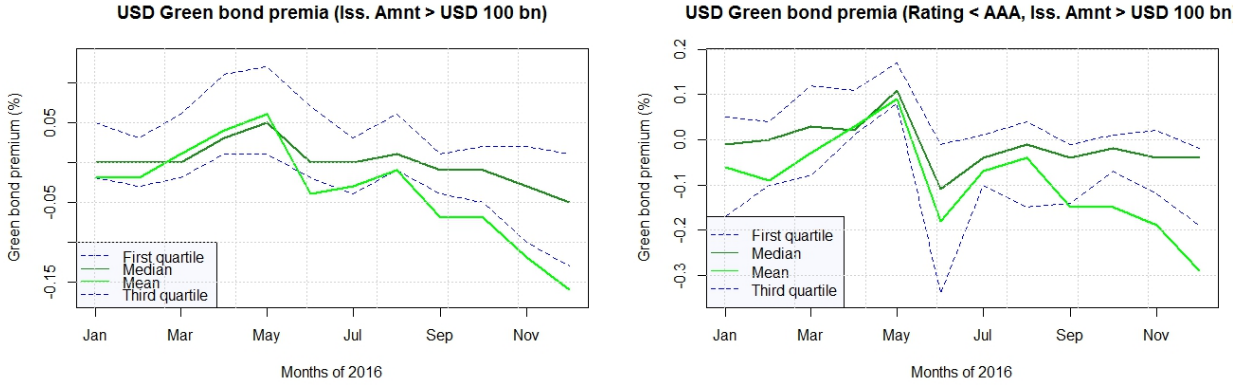
One of the main issues which arises in this section is the question as to whether or not a green bond premium remains stable with time. A fixed time effect is added to the individual effect in the first regression procedure via a Within two-way model, taking the bid-ask spread as the liquidity-control variable. The estimated bid-ask spread parameter is found to be highly 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, which means that there might not be any daily time fixed effect involved in the green bond premium.

However, upon applying the same two-step 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 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.



(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.

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 15 and 14). 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.

Another potential concern is whether the green bond premium reflects a market risk premium over time. Although the daily time effect of this variable 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 last question about the robustness which arises is about 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. 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 16, show that the green bond premia are again 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.

The robustness checks performed here make it possible to state that the general regressions used to estimate and explain the green bond premia are appropriate and that the present approximation of the conventional bond yield is satisfactory. However, as might be expected, the negative green bond premium is found to vary with time.

7 Discussion

The results obtained in this study on the green bond premium in supranational, agencies, municipal, corporate and financial bonds point to the pressure exerted by the demand on green debt. In various market segments, such as Financial bonds, AA bonds or with a small issued amount (greater than USD 100 million) in the case of Investment Grade EUR bonds and those with a high yield or a high rating in the case of Investment Grade USD bonds, the negative green bond premium observed indicates that the buying pressure relative to the supply capacity is greater in the case of green bonds than conventional bonds. This situation reflects the strong interest of investors willing to fund the environmental transition in green bonds. Although the green bonds studied here were issued at a comparable yield to that of a conventional bond with the same characteristics originating from the same issuer (see OECD (2015c)), the secondary market structure highlights the potential for increasing the green bond issuance and offering a primary yield which is slightly lower than that observed on the conventional bond curve. 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 (2015c)), is consistent with political ambitions and financial players' recommendations. A consortium of European sustainable finance 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)). Moreover, politicians can play a crucial role by providing green project developers with more attractive conditions and unlocking the full potential of the green bond market[26].

The deficit in terms of green bond issuance relative to the investment demand may be attributable to several factors. On the issuers' side, the emission of green bonds obviously depends on the existence of green projects and is subject to the obligation of disclosing, tracking and reporting the use of proceeds. These restraints are more binding than those governing regular bond emissions and may reduce the volumes issued. On the investors' side, the appetite for green debt is being fed by public and private initiatives designed to redirect investments towards low carbon assets. In terms of the dynamics involved, we have observed here that the average and median values of the green bond premia were negative, stable in the case of EUR bonds and

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[26] First, national and supranational authorities should 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)). Fostering risk pooling, through ABS in particular, would also enable minor players to enter the green bond market. A third 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). Fourthly, governments should set up a beneficial tax regime (tax savings on interest costs or subsidies) for green bond issuers in order to voluntarily lower the net cost of debt for investors in low-carbon projects. Tax support measures have to be weighed up against traditional climate support facilities, however, and they could be improved by reducing the present tax exemptions for those promoting fossil energies. Lastly, the world's monetary authorities (the European Central Bank, the Bank of England, the Bank of Japan, etc.) could well support the development of green projects and maintain a low cost of debt by prioritizing the purchase of green bonds in their quantitative easing programs. This takes on even greater significance, as Mark Carney, the President of the Bank of England, has stressed, in the light of the necessary integration of environmental risks into the financial risk management policy of a Central Bank. The key role of Central Banks in supporting low-carbon projects has also recently been stressed by Campiglio (2016), who has recommended that banks' reserve requirements should be decreased, depending on the amount of green lending, as well as by Aglietta and Espagne (2015), who have suggested the creation of green certificates, in exchange for lending money to green projects, which are eligible for Central Banks' asset purchase program.

on the decrease in that of USD bonds at the end of the year 2016. If the green bond supply increases faster than the investment demand, the green bond premium may gradually wane; whereas an increasing demand for greater issuance might increase the absolute value of the negative premia, and thus decrease the cost of capital, which would be an advantage for green projects.

However, there is a misalignment of interests between bond issuers and investors. While a negative premium favors the issuing of green debt, it 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 of 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. If the equivalent conventional debt gives greater yields, green debt will be forsaken by those investors who do not have to meet any green investment obligations. In addition to winding down the funding of low-carbon projects, a negative premium would therefore increase the concentration of green bond risks among the few existing green investors, and thus potentially hike up the level of systemic risk. Consequently, policy makers must address the intricate two-fold challenge of maintaining a low cost of capital for sustainable projects and encouraging green investors to opt for green bonds when investing in a company's debt.

In order to maintain an incentive for investors and shift large capital flows to support the environmental transition, governments and supranational authorities could use two levers: amending prudential regulations and implementing fiscal support policies. Mitigating the cost of capital to support corporate green bonds in keeping with Solvency 2 and Basel 3 would create an incentive for institutional investors that might compensate for the negative green bond premium by creating a solvency surplus. In addition, reducing the cost of capital would not be contrary to the logics of prudential regulation, since a green asset is immune to the legal and financial risks associated with the environmental transition. The French Banking Federation proposed such a mechanism of capital relief, called the "Green supporting factor", via a mitigation of the Risk-Weighted Assets (RWA) for the investments made by banks in green assets (Fédération Bancaire Française (2016)).

The second option would be to offer to green bond investors a tax advantage in order to enhance the net yield of the security. Supporting investors in sustainable projects is all the more important as the term of investment is generally shorter than the horizon of environmental risk mitigation.

A two-fold action of this kind on the net cost of debt for issuers and the net yield for investors might trigger a virtuous circle of increasing financial cash flows converging towards more green debt emission.

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 a completely equivalent non-green bond with the same characteristics emitted by the same issuer. To ensure high-quality data, we study a sample accounting for one fifth of the green bonds issued worldwide in December 2016. The green bond premium is defined as the difference in yield between these two bonds. The main objective of this article is to determine the value of the green bond premium and to explain it.

The green bond premium is estimated using a matched pair approach. The difference in yield between a green bond and an equivalent synthetic conventional bond is first calculated, and this difference is then controlled by the difference in liquidity between the two kinds of bonds, using a fixed effect regression model. Lastly, the green bond premium is explained by the structure of the curve and the characteristics of the bond.

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. Thirdly, there is a regrettable lack of incentive for investors with no special obligations to make green investments to opt for green debt. In order to sustain and broadly develop an active and lively green bond market, public authorities must therefore set up appropriate regulatory and fiscal policies for voluntarily enhancing the net green bond yield.

The methodology of this paper has been first 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 improve the quality of the data collected, either by studying larger numbers of bonds and those with a longer history or by using intraday data and indicators to better control the illiquidity mismatch. This would make it possible to draw up highly accurate green bond premium curves. 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 public policy.

Appendix

	Number of bonds				
	AAA	**AA**	**A**	**BBB**	**Total**
AUD	5	3	4		12
BRL	11		6		17
CAD	2				2
CHF	1				1
CNY			1		1
EUR	12	2	10	2	26
GBP	2				2
IDR	7				7
INR	12		6		18
JPY			2		2
MXN	2		3		5
NOK	1				1
NZD			1		1
RUB	3				3
SEK	2		1		3
TRY	3				3
USD	15	2	9	3	29
ZAR	2				2
Total	80	7	43	5	135

Table 8 – **Number of bonds broken down in terms of rating and currency**. This table gives the number of green bonds depending on the ratings and the currency of emission. The vast majority of green bonds are AAA (80 bonds) and the most frequently occurring currencies if the bonds are EUR (26 bonds) and USD (29 bonds).

	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 9 – **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 10 – **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 11 – **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 12 – **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 $\widehat{p}_i(\Delta \text{BA})$. 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 three modalities of which are Government (reference modality), Financials and Utilities. Currency is also a qualitative variable standing for the currency of issuance. Table 10 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 13 – **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 14 – **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 15 – **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 16 – **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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Supplementary material

Green bonds							
ISIN	**Issuer name**	**Cur.**	**Coupon**	**Maturity**	**Amount issued**	**Issuance date**	**Rating**
XS0520248112	AFRICAN DEVELOPMENT BANK	BRL	0.50	28-Jul-2017	37 100 000	28-Jul-2010	AAA
XS0529195926	AFRICAN DEVELOPMENT BANK	BRL	0.50	25-Aug-2017	32 800 000	26-Aug-2010	AAA
XS0541912605	AFRICAN DEVELOPMENT BANK	BRL	0.50	20-Oct-2017	29 000 000	19-Oct-2010	AAA
US00828EBJ73	AFRICAN DEVELOPMENT BANK	USD	1.38	17-Dec-2018	500 000 000	17-Dec-2015	AAA
XS1111084718	AGENCE FRANCAISE DEVELOP	EUR	1.38	17-Sep-2024	1 000 000 000	17-Sep-2014	AA
AU3CB0230100	AUST & NZ BANKING GROUP	AUD	3.25	3-Jun-2020	600 000 000	3-Jun-2015	AA
XS0536540023	ASIAN DEVELOPMENT BANK	BRL	0.50	29-Sep-2017	124 500 000	29-Sep-2010	AAA
XS0536541005	ASIAN DEVELOPMENT BANK	TRY	0.50	29-Sep-2017	65 000 000	29-Sep-2010	AAA
FR0013067170	BPCE SA	EUR	1.13	14-Dec-2022	300 000 000	14-Dec-2015	A
XS1237362907	EUROPEAN BK RECON & DEV	INR	5.49	10-Jan-2018	1 440 000 000	30-Jun-2015	AAA
XS1250896401	EUROPEAN BK RECON & DEV	INR	5.85	28-Jan-2019	1 100 000 000	27-Jul-2015	AAA
XS1193125314	EUROPEAN BK RECON & DEV	IDR	6.38	27-Mar-2019	200 000 000 000	26-Mar-2015	AAA
XS1208591880	EUROPEAN BK RECON & DEV	IDR	6.88	24-Apr-2019	270 000 000 000	23-Apr-2015	AAA
XS1224586872	EUROPEAN BK RECON & DEV	IDR	6.91	28-May-2019	230 000 000 000	28-May-2015	AAA
XS1245283483	EUROPEAN BK RECON & DEV	RUB	8.75	10-Jul-2018	50 000 000	9-Jul-2015	AAA
XS0953030482	EUROPEAN BK RECON & DEV	BRL	8.01	26-May-2017	155 000 000	8-Aug-2013	AAA
XS1351517260	EUROPEAN BK RECON & DEV	IDR	8.46	19-Feb-2019	180 000 000 000	18-Feb-2016	AAA
XS1324201497	EUROPEAN BK RECON & DEV	IDR	8.66	17-Dec-2018	170 000 000 000	14-Dec-2015	AAA
XS1081203124	EUROPEAN BK RECON & DEV	BRL	8.85	28-Jul-2017	110 000 000	25-Jul-2014	AAA
XS1204483660	EUROPEAN BK RECON & DEV	RUB	9.05	18-Apr-2017	125 000 000	16-Apr-2015	AAA
XS1140894434	EUROPEAN BK RECON & DEV	BRL	9.06	28-Jun-2017	45 000 000	18-Dec-2014	AAA
XS1039383093	EUROPEAN BK RECON & DEV	BRL	9.12	28-Sep-2017	93 000 000	20-Mar-2014	AAA
XS1195204950	EUROPEAN BK RECON & DEV	BRL	9.21	30-Oct-2017	48 000 000	20-Mar-2015	AAA
US30216BER96	EXPORT DEVELOPMNT CANADA	USD	0.88	30-Jan-2017	300 000 000	30-Jan-2014	AAA
US30216BFY39	EXPORT DEVELOPMNT CANADA	USD	1.25	10-Dec-2018	300 000 000	8-Dec-2015	AAA
FR0011637586	ELECTRICITE DE FRANCE SA	EUR	2.25	27-Apr-2021	1 400 000 000	27-Nov-2013	A
XS1314336204	EUROPEAN INVESTMENT BANK	CAD	1.25	5-Nov-2020	500 000 000	5-Nov-2015	AAA
US29878TCS15	EUROPEAN INVESTMENT BANK	CAD	1.25	5-Nov-2020	500 000 000	5-Nov-2015	AAA
XS1107718279	EUROPEAN INVESTMENT BANK	EUR	1.25	13-Nov-2026	1 500 000 000	10-Sep-2014	AAA
LU0953782009	EUROPEAN INVESTMENT BANK	EUR	1.38	15-Nov-2019	3 000 000 000	18-Jul-2013	AAA
CH0233004172	EUROPEAN INVESTMENT BANK	CHF	1.63	4-Feb-2025	350 000 000	4-Feb-2014	AAA
US298785GQ39	EUROPEAN INVESTMENT BANK	USD	2.50	15-Oct-2024	1 000 000 000	15-Oct-2014	AAA
XS1051861851	EUROPEAN INVESTMENT BANK	GBP	2.25	7-Mar-2020	1 800 000 000	8-Apr-2014	AAA
XS0773059042	EUROPEAN INVESTMENT BANK	SEK	3.00	23-Apr-2019	3 750 000 000	23-Apr-2012	AAA
XS1198278175	EUROPEAN INVESTMENT BANK	TRY	8.50	27-Mar-2019	175 000 000	12-Mar-2015	AAA
US302154BG39	EXPORT-IMPORT BK KOREA	USD	1.75	27-Feb-2018	500 000 000	27-Feb-2013	AA
US302154BZ10	EXPORT-IMPORT BANK KOREA	USD	2.13	11-Feb-2021	400 000 000	11-Feb-2016	AA
FR0011911239	ENGIE SA	EUR	1.38	19-May-2020	1 200 000 000	19-May-2014	A
XS1209864229	EXPORT-IMPORT BK INDIA	USD	2.75	1-Apr-2020	500 000 000	1-Apr-2015	BBB
XS1057055060	IBERDROLA INTL BV	EUR	2.50	24-Oct-2022	750 000 000	24-Apr-2014	BBB
XS1196261371	INTL FINANCE CORP	BRL	9.31	2-Apr-2020	14 250 000	31-Mar-2015	AAA
XS1311459694	KFW	EUR	0.13	27-Oct-2020	1 500 000 000	27-Oct-2015	AAA
XS1087815483	KFW	EUR	0.38	22-Jul-2019	1 500 000 000	22-Jul-2014	AAA
XS1333145040	KFW	SEK	0.59	14-Dec-2020	1 000 000 000	14-Dec-2015	AAA
US500769GF56	KFW	USD	1.75	15-Oct-2019	1 500 000 000	15-Oct-2014	AAA
XS1268337844	KFW	GBP	1.63	5-Jun-2020	500 000 000	30-Jul-2015	AAA
US500769GU24	KFW	USD	1.88	30-Nov-2020	1 000 000 000	18-Nov-2015	AAA

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AU000KFWHAC9	KFW	AUD	2.40	2-Jul-2020	600 000 000	2-Apr-2015	AAA
AU3CB0226090	NATIONAL AUSTRALIA BANK	AUD	4.00	16-Dec-2021	300 000 000	16-Dec-2014	AA
XS1083955911	NEDER WATERSCHAPSBANK	EUR	0.63	3-Jul-2019	500 000 000	3-Jul-2014	AAA
XS1284550941	NEDER WATERSCHAPSBANK	EUR	1.00	3-Sep-2025	1 000 000 000	3-Sep-2015	AAA
DE000NWB0AB2	NRW.BANK	EUR	0.25	5-Nov-2018	500 000 000	4-Nov-2014	AAA
DE000NWB0AC0	NRW.BANK	EUR	0.88	10-Nov-2025	500 000 000	10-Nov-2015	AAA
NO0010752702	OSLO KOMMUNE	NOK	2.35	4-Sep-2024	1 500 000 000	4-Dec-2015	AAA
XS0963399257	LANDWIRTSCH. RENTENBANK	EUR	1.46	20-Aug-2020	50 000 000	20-Aug-2013	AAA
US865622BY94	SUMITOMO MITSUI BANKING	USD	2.45	20-Oct-2020	500 000 000	20-Oct-2015	A
FR0013054897	VILLE DE PARIS	EUR	1.75	25-May-2031	300 000 000	18-Nov-2015	AA
INE528G08279	YES BANK LTD	INR	8.85	24-Feb-2025	10 000 000 000	24-Feb-2015	A
XS0982561481	CREDIT AGRICOLE CIB	JPY	0.35	26-Oct-2017	13 360 000 000	30-Oct-2013	A
XS0984245042	CREDIT AGRICOLE CIB	MXN	4.22	26-Nov-2018	260 000 000	25-Nov-2013	A
XS1114368787	CREDIT AGRICOLE CIB	INR	6.00	29-Oct-2019	1 650 000 000	28-Oct-2014	A
XS1107647239	CREDIT AGRICOLE CIB	BRL	9.05	26-Sep-2017	21 000 000	25-Sep-2014	A
XS1140835775	CREDIT AGRICOLE CIB	BRL	9.20	28-Nov-2018	43 200 000	28-Nov-2014	A
XS1070445827	CREDIT AGRICOLE CIB	BRL	9.24	25-Sep-2017	11 100 000	26-Jun-2014	A
XS1244060486	ABN AMRO BANK NV	EUR	0.75	9-Jun-2020	500 000 000	9-Jun-2015	A
XS1179276958	INTL BK RECON & DEVELOP	INR	4.00	27-Feb-2020	436 000 000	26-Feb-2015	AAA
XS0684954232	INTL BK RECON & DEVELOP	AUD	4.45	6-Oct-2021	10 000 000	5-Oct-2011	AAA
XS1202767866	INTL BK RECON & DEVELOP	INR	4.80	21-Apr-2020	63 000 000	20-Apr-2015	AAA
XS1342540090	INTL BK RECON & DEVELOP	INR	5.80	29-Jan-2021	607 000 000	28-Jan-2016	AAA
XS1325600994	IDBI BANK LTD/DIFC DUBAI	USD	4.25	30-Nov-2020	350 000 000	30-Nov-2015	BBB
US45950VHE92	INTL FINANCE CORP	USD	1.25	27-Nov-2018	500 000 000	27-Nov-2015	AAA
XS1307860574	INTL FINANCE CORP	TRY	8.65	30-Nov-2017	7 300 000	27-Nov-2015	AAA
XS0873237068	INTL BK RECON & DEVELOP	ZAR	0.50	31-Jan-2018	83 000 000	30-Jan-2013	AAA
XS0887320900	INTL BK RECON & DEVELOP	MXN	0.50	28-Feb-2019	50 000 000	27-Feb-2013	AAA
XS0809448375	INTL BK RECON & DEVELOP	RUB	6.50	26-Jul-2019	750 000 000	26-Jul-2012	AAA
XS1066979490	INTL BK RECON & DEVELOP	BRL	9.27	21-May-2018	465 500 000	21-May-2014	AAA
XS1075369816	CREDIT AGRICOLE CIB	BRL	9.45	26-Jun-2017	17 000 000	25-Jun-2014	A
XS0927890128	CREDIT AGRICOLE CIB	MXN	0.50	18-Dec-2017	70 000 000	17-Jun-2013	A
XS1069942263	CREDIT AGRICOLE CIB	JPY	0.30	4-Jun-2018	7 664 000 000	2-Jun-2014	A
XS1002078266	CREDIT AGRICOLE CIB	USD	2.01	18-Dec-2018	52 000 000	18-Dec-2013	A
XS1079727811	CREDIT AGRICOLE CIB	AUD	3.37	20-Jun-2018	45 200 000	2-Jul-2014	A
XS1136642235	CREDIT AGRICOLE CIB	AUD	3.47	21-Nov-2019	32 000 000	25-Nov-2014	A
XS1002079587	CREDIT AGRICOLE CIB	AUD	4.54	18-Dec-2018	60 300 000	18-Dec-2013	A
XS1174161197	CREDIT AGRICOLE CIB	INR	5.00	24-Feb-2020	1 250 000 000	23-Feb-2015	A
XS1279275298	CREDIT AGRICOLE CIB	INR	6.00	29-Jan-2019	110 000 000	28-Jan-2016	A
US06051GFR56	BANK OF AMERICA CORP	USD	1.95	12-May-2018	600 000 000	12-May-2015	A
XS1324217733	ING BANK NV	EUR	0.75	24-Nov-2020	500 000 000	24-Nov-2015	A
US44987DAJ54	ING BANK NV	USD	2.00	26-Nov-2018	800 000 000	24-Nov-2015	A
US44987CAJ71	ING BANK NV	USD	2.00	26-Nov-2018	800 000 000	24-Nov-2015	A
XS1161418501	INTL BK RECON & DEVELOP	INR	4.20	30-Jan-2020	348 500 000	29-Jan-2015	AAA
XS1218772793	INTL BK RECON & DEVELOP	INR	5.20	22-May-2020	63 000 000	21-May-2015	AAA
XS1379598284	INTL BK RECON & DEVELOP	INR	5.65	30-Mar-2021	323 700 000	30-Mar-2016	AAA
US6174468B80	MORGAN STANLEY	USD	2.20	7-Dec-2018	500 000 000	8-Jun-2015	A
XS0994434487	EUROPEAN INVESTMENT BANK	ZAR	6.75	15-Sep-2017	2 300 000 000	19-Nov-2013	AAA
XS1070709586	INTL BK RECON & DEVELOP	AUD	3.01	3-Jun-2019	24 200 000	2-Jun-2014	AAA
XS1136641930	CREDIT AGRICOLE CIB	MXN	4.55	21-Nov-2019	350 000 000	25-Nov-2014	A
XS1140833309	CREDIT AGRICOLE CIB	USD	1.56	27-Nov-2019	16 900 000	28-Nov-2014	A
XS1218319702	UNIBAIL-RODAMCO SE	EUR	1.00	14-Mar-2025	500 000 000	15-Apr-2015	A
AU3CB0220424	INTL BK RECON & DEVELOP	AUD	3.50	29-Apr-2019	300 000 000	29-Apr-2014	AAA

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XS1280834992	EUROPEAN INVESTMENT BANK	EUR	0.50	15-Nov-2023	1 900 000 000	27-Aug-2015	AAA
XS1422841202	ABN AMRO BANK NV	EUR	0.63	31-May-2022	500 000 000	31-May-2016	A
XS1367226385	CREDIT AGRICOLE CIB	AUD	2.30	18-Jun-2020	49 100 000	24-Jun-2016	A
XS1367226468	CREDIT AGRICOLE CIB	NZD	2.82	18-Jun-2020	36 000 000	24-Jun-2016	A
XS1417410989	CREDIT AGRICOLE CIB	INR	5.45	18-Nov-2020	65 000 000	17-Nov-2016	A
XS1367225577	CREDIT AGRICOLE CIB	BRL	7.80	24-Jan-2020	10 000 000	28-Jun-2016	A
XS1367227359	CREDIT AGRICOLE CIB	BRL	8.20	28-Jun-2019	3 300 000	29-Jun-2016	A
US045167DQ35	ASIAN DEVELOPMENT BANK	USD	1.00	16-Aug-2019	800 000 000	16-Aug-2016	AAA
INE296A07LL7	BAJAJ FINANCE LTD	INR	8.55	14-Jul-2021	100 000 000	14-Jul-2016	A
XS1437622548	BANK OF CHINA/LUXEMBOURG	USD	1.88	12-Jul-2019	500 000 000	12-Jul-2016	A
XS1437622977	BANK OF CHINA/LUXEMBOURG	USD	2.25	12-Jul-2021	1 000 000 000	12-Jul-2016	A
XS1437844100	BANK OF CHINA/NEW YORK	CNY	3.60	12-Jul-2018	1 500 000 000	12-Jul-2016	A
XS1527753187	BNP PARIBAS	EUR	0.50	1-Jun-2022	500 000 000	1-Dec-2016	A
XS1383852057	EUROPEAN BK RECON & DEV	INR	5.55	15-Oct-2018	886 000 000	25-Apr-2016	AAA
XS1493432295	EUROPEAN BK RECON & DEV	IDR	5.78	15-Apr-2019	160 000 000 000	24-Oct-2016	AAA
XS1418779929	EUROPEAN BK RECON & DEV	IDR	6.55	17-Jun-2019	130 000 000 000	13-Jun-2016	AAA
XS1490726590	IBERDROLA INTL BV	EUR	0.38	15-Sep-2025	700 000 000	15-Sep-2016	BBB
US45905UWE09	INTL BK RECON & DEVELOP	USD	1.01	1-Oct-2018	280 000 000	21-Apr-2016	AAA
US45905UVR21	INTL BK RECON & DEVELOP	USD	1.17	29-Jan-2019	45 000 000	29-Mar-2016	AAA
XS1432564133	INTL BK RECON & DEVELOP	INR	5.50	28-Jun-2021	200 000 000	29-Jun-2016	AAA
XS1401328965	INTL BK RECON & DEVELOP	INR	5.32	2-Jun-2021	835 000 000	27-May-2016	AAA
XS1392102551	INTL BK RECON & DEVELOP	INR	5.60	28-Apr-2021	300 000 000	27-Apr-2016	AAA
XS1402169848	INTL FINANCE CORP	MXN	4.75	29-Apr-2021	750 000 000	29-Apr-2016	AAA
US50048MCD02	KOMMUNALBANKEN AS	USD	1.38	26-Oct-2020	500 000 000	26-Oct-2016	AAA
XS1508672828	KOMMUNALBANKEN AS	USD	1.38	26-Oct-2020	500 000 000	26-Oct-2016	AAA
XS1414146669	KFW	EUR	0.05	30-May-2024	1 000 000 000	20-May-2016	AAA
US500769HD99	KFW	USD	2.00	30-Nov-2021	1 500 000 000	30-Nov-2016	AAA
XS1383831648	KOMMUNINVEST I SVERIGE	USD	1.50	23-Apr-2019	600 000 000	22-Mar-2016	AAA
US50046PAU93	KOMMUNINVEST I SVERIGE	USD	1.50	23-Apr-2019	600 000 000	22-Mar-2016	AAA
DE000NWB0AD8	NRW.BANK	EUR	0.38	17-Nov-2026	500 000 000	17-Nov-2016	AAA
XS1502438820	COOPERATIEVE RABOBANK UA	EUR	0.13	11-Oct-2021	500 000 000	11-Oct-2016	AA
XS1436518606	SBAB BANK AB	SEK	1.05	23-Jun-2021	1 000 000 000	23-Jun-2016	A
XS1500337644	SOCIETE GENERALE	EUR	0.13	5-Oct-2021	500 000 000	5-Oct-2016	A
AU0000XVGHK0	TREASURY CORP VICTORIA	AUD	1.75	27-Jul-2021	300 000 000	27-Jul-2016	AAA
XS1412393172	TURKIYE SINAI KALKINMA B	USD	4.88	18-May-2021	300 000 000	18-May-2016	BBB
AU3CB0237683	WESTPAC BANKING CORP	AUD	3.10	3-Jun-2021	500 000 000	3-Jun-2016	AA

Table 18 – **Characteristics of the green bond sample.** This table gives the details and characteristics of our full sample of 135 green bonds.

Month	Number of green bonds
April-12	2
May-12	3
June-12	3
July-12	3
August-12	3
September-12	3
October-12	3
November-12	3
December-12	3
January-13	3
February-13	3
March-13	3
April-13	3
May-13	3
June-13	4
July-13	5
August-13	8
September-13	8
October-13	8
November-13	13
December-13	11
January-14	13
February-14	12
March-14	13
April-14	18
May-14	19
June-14	21
July-14	24
August-14	24
September-14	27
October-14	28
November-14	30
December-14	33
January-15	34
February-15	35
March-15	42
April-15	43
May-15	47
June-15	50
July-15	52
August-15	52
September-15	55
October-15	56
November-15	63
December-15	74
January-16	80
February-16	82
March-16	82
April-16	90
May-16	97
June-16	104
July-16	114
August-16	118
September-16	121
October-16	126
November-16	131
December-16	131

Table 19 – **Number of green bonds analyzed per month**. This table gives the number of green bonds analyzed on a monthly basis, from April 2012 to August 2016.

	$\Delta\tilde{y}_{i,t}$ **(in percentage points)**				
	AAA	**AA**	**A**	**BBB**	**Average**
AUD	0.01	-0.07	-0.49		-0.18
BRL	0.07		0.77		0.32
CAD	0.00				0.00
CHF	0.00				0.00
CNY			-0.04		-0.04
EUR	0.01	-0.05	-0.04	0.01	-0.01
GBP	0.00				0.00
IDR	-0.55				-0.55
INR	-0.43		0.32		-0.18
JPY			-0.12		-0.12
MXN	-0.52		-0.07		-0.25
NOK	0.03				0.03
NZD			-0.04		-0.04
RUB	-0.66				-0.66
SEK	0.00		-0.01		0.00
TRY	0.57				0.57
USD	-0.02	0.04	-0.26	-0.10	-0.10
ZAR	0.12				0.12
Average	-0.12	-0.03	0.03	-0.06	-0.06

Table 20 – **Average yield difference ($\Delta\tilde{y}_{i,t}$) broken down depending on the rating and currency**. This table gives the average value of $\Delta\tilde{y}_{i,t}$ with time depending on the rating and the currency of each pair of bonds.

		Panel : $\Delta\tilde{y}$ controled by ΔBA		
		Statistic	**P Value**	**Conclusion**
Fixed vs. Random effect	Hausman's test	14.906 (df=1)	0.0001	Fixed effect
Individual effect	F test	121.09 (df1=134, df2=43309)	$<2.2.10^{-16}$	Individual effect
	Wooldridge's test	2.43	0.015	Individual effect
	Breusch-Pagan's test	135100000 (df=1)	$<2.2.10^{-16}$	Individual effect
	Honda's test	11623	$<2.2.10^{-16}$	Individual effect
Serial correlation	Breusch-Godfrey Wooldridge's test	38044 (df=11)	$<2.2.10^{-16}$	Serial correlation
	Durbin Watson's test	0.1315	$<2.2.10^{-16}$	Serial correlation
	Wooldridge's test for AR(1)	12326	$<2.2.10^{-16}$	AR(1) serial correlation
Heteroscedasticity	Breusch-Pagan's test	881750 (df=135)	$<2.2.10^{-16}$	Heteroscedastitiy

Table 21 – **Tests of step 1 regression controlled with ΔBA**. This table shows the tests performed in the step 1 regression, controlled by the difference in the bid-ask spread: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta\text{BA}_{i,t} + \varepsilon_{i,t}$. The results of the tests are presented in terms of the statistics, the P-Values and their interpretation. The results show that the fixed effect regression is the most suitable procedure here. They also indicate the existence of an individual effect but no time effect. Lastly, the tests show the presence of serial correlation and heteroscedasticity.

		Panel : $\Delta\tilde{y}$ controled by ΔZTD		
		Statistic	**P Value**	**Conclusion**
Fixed vs. Random effect	Hausman's test	0.05 (df=1)	0.82	Random effect
Individual effect	F test	114.8 (df1=134, df2=43309)	$<2.2.10^{-16}$	Individual effect
	Wooldridge's test	2.42	0.015	Individual effect
	Breusch-Pagan's test	13680000 (df=1)	$<2.2.10^{-16}$	Individual effect
	Honda's test	11475	$<2.2.10^{-16}$	Individual effect
Serial correlation	Breusch-Godfrey Wooldridge's test	37862 (df=11)	$<2.2.10^{-16}$	Serial correlation
	Durbin Watson's test	0.1363	$<2.2.10^{-16}$	Serial correlation
	Wooldridge's test for AR(1)	12395	$<2.2.10^{-16}$	AR(1) serial correlation
Heteroscedasticity	Breusch-Pagan's test	862250 (df=135)	$<2.2.10^{-16}$	Heteroscedastitiy

Table 22 – **Tests of step 1 regression controlled with ΔZTD**. This table shows the tests performed in the step 1 regression controlled by the difference in the number of zero-trading days: $\Delta\tilde{y}_{i,t} = p_i + \beta\Delta\text{ZTD}_{i,t} + \varepsilon_{i,t}$. The results of these tests are presented in the form of the statistics, the P-Values and their interpretation. The results show that the random effect regression is more efficient here than a fixed effect regression. They also indicate the presence of an individual effect but no time effects. Lastly, these tests show the presence of serial correlation and heteroscedasticity.

Green bond premia (in percentage points)				
ISIN	**FEGLS** $\widehat{p}_i(\Delta\mathbf{BA})$	**FE** $\widehat{p}_i(\Delta\mathbf{BA})$	**FEGLS** $\widehat{p}_i(\Delta\mathbf{ZTD})$	**FE** $\widehat{p}_i(\Delta\mathbf{ZTD})$
AU0000XVGHK0	-0.09	-0.09	-0.07	-0.07
AU000KFWHAC9	0.00	0.00	0.00	0.00
AU3CB0220424	-0.02	-0.02	-0.01	-0.01
AU3CB0226090	0.07	0.07	0.09	0.09
AU3CB0230100	-0.03	-0.03	-0.04	-0.04
AU3CB0237683	-0.27	-0.27	-0.26	-0.26
CH0233004172	0.00	0.00	0.00	0.00
DE000NWB0AB2	-0.02	-0.02	-0.01	-0.01
DE000NWB0AC0	0.00	0.00	0.00	0.00
DE000NWB0AD8	-0.02	-0.02	-0.02	-0.02
FR0011637586	-0.01	-0.01	-0.01	-0.01
FR0011911239	0.01	0.01	0.03	0.03
FR0013054897	-0.05	-0.05	-0.08	-0.08
FR0013067170	0.01	0.01	0.01	0.01
INE296A07LL7	-0.02	-0.02	-0.02	-0.02
INE528G08279	0.00	0.00	0.00	0.00
LU0953782009	0.01	0.01	-0.01	-0.01
NO0010752702	0.02	0.02	0.03	0.03
US00828EBJ73	-0.04	-0.04	0.02	0.02
US045167DQ35	0.01	0.01	0.02	0.02
US06051GFR56	0.04	0.04	0.08	0.08
US298785GQ39	-0.02	-0.02	-0.02	-0.02
US29878TCS15	-0.01	-0.01	0.00	0.00
US302154BG39	0.07	0.07	0.09	0.09
US302154BZ10	-0.01	-0.01	-0.01	-0.01
US30216BER96	0.03	0.03	0.04	0.04
US30216BFY39	0.04	0.04	0.03	0.03
US44987CAJ71	-0.02	-0.02	-0.02	-0.02
US44987DAJ54	-0.02	-0.02	-0.04	-0.04
US45905UVR21	-0.04	-0.04	-0.03	-0.03
US45905UWE09	0.01	0.01	0.05	0.05
US45950VHE92	0.12	0.12	0.12	0.12
US50046PAU93	-0.14	-0.14	-0.13	-0.13
US50048MCD02	-0.09	-0.09	-0.09	-0.09
US500769GF56	-0.01	-0.01	-0.01	-0.01
US500769GU24	0.00	0.00	0.00	0.00
US500769HD99	-0.06	-0.06	-0.05	-0.05
US6174468B80	-0.48	-0.48	-0.49	-0.49
US865622BY94	-0.01	-0.01	-0.03	-0.03
XS0520248112	-0.22	-0.22	-0.07	-0.07
XS0529195926	-0.10	-0.10	-0.09	-0.09
XS0536540023	2.39	2.39	2.29	2.29
XS0536541005	0.02	0.02	-0.09	-0.09
XS0541912605	0.15	0.15	0.04	0.04
XS0684954232	-0.10	-0.10	-0.03	-0.03
XS0773059042	-0.04	-0.04	-0.02	-0.02
XS0809448375	-0.05	-0.05	-0.26	-0.26
XS0873237068	0.25	0.25	0.30	0.30
XS0887320900	0.24	0.24	0.02	0.02

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XS0927890128	0.00	0.00	-0.02	-0.02
XS0953030482	-0.65	-0.65	-0.34	-0.34
XS0963399257	0.07	0.07	0.08	0.08
XS0982561481	-0.02	-0.02	-0.02	-0.02
XS0984245042	0.00	0.00	0.00	0.00
XS0994434487	-0.03	-0.03	-0.07	-0.07
XS1002078266	-1.02	-1.02	-0.91	-0.91
XS1002079587	-0.17	-0.17	0.00	0.00
XS1039383093	-0.29	-0.29	-0.29	-0.29
XS1051861851	-0.01	-0.01	-0.01	-0.01
XS1057055060	0.00	0.00	0.00	0.00
XS1066979490	0.96	0.96	0.95	0.95
XS1069942263	-0.24	-0.24	-0.23	-0.23
XS1070445827	1.22	1.22	1.33	1.33
XS1070709586	0.17	0.17	0.17	0.17
XS1075369816	0.10	0.10	0.04	0.04
XS1079727811	-0.63	-0.63	-0.46	-0.46
XS1081203124	0.02	0.02	0.01	0.01
XS1083955911	0.00	0.00	0.00	0.00
XS1087815483	0.00	0.00	0.01	0.01
XS1107647239	0.00	0.00	0.00	0.00
XS1107718279	0.01	0.01	0.00	0.00
XS1111084718	-0.02	-0.02	-0.02	-0.02
XS1114368787	0.08	0.08	0.09	0.09
XS1136641930	-0.22	-0.22	-0.18	-0.18
XS1136642235	-0.46	-0.46	-0.32	-0.32
XS1140833309	-0.72	-0.72	-0.68	-0.68
XS1140835775	1.35	1.35	1.46	1.46
XS1140894434	0.31	0.31	0.22	0.22
XS1161418501	-2.66	-2.66	-2.59	-2.59
XS1174161197	0.16	0.16	0.16	0.16
XS1179276958	-0.41	-0.41	-0.32	-0.32
XS1193125314	-0.79	-0.79	-0.33	-0.33
XS1195204950	-0.39	-0.39	-0.28	-0.28
XS1196261371	-1.78	-1.78	-1.70	-1.70
XS1198278175	0.06	0.06	0.10	0.10
XS1202767866	-0.11	-0.11	-0.05	-0.05
XS1204483660	-0.78	-0.78	-1.47	-1.47
XS1208591880	-0.08	-0.08	-0.26	-0.26
XS1209864229	0.11	0.11	0.10	0.10
XS1218319702	-0.09	-0.09	-0.10	-0.10
XS1218772793	-0.04	-0.04	-0.01	-0.01
XS1224586872	-0.08	-0.08	-0.23	-0.23
XS1237362907	-0.63	-0.63	-0.62	-0.62
XS1244060486	-0.16	-0.16	-0.14	-0.14
XS1245283483	-0.26	-0.26	-0.27	-0.27
XS1250896401	-0.51	-0.51	-0.42	-0.42
XS1268337844	0.02	0.02	0.02	0.02
XS1279275298	-0.01	-0.01	0.00	0.00
XS1280834992	0.04	0.04	0.04	0.04
XS1284550941	0.01	0.01	0.02	0.02
XS1307860574	1.61	1.61	1.71	1.71

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XS1311459694	0.07	0.07	0.06	0.06
XS1314336204	-0.01	-0.01	0.01	0.01
XS1324201497	-0.95	-0.95	-0.30	-0.30
XS1324217733	-0.05	-0.05	-0.05	-0.05
XS1325600994	-0.21	-0.21	-0.13	-0.13
XS1333145040	0.10	0.10	0.03	0.03
XS1342540090	0.42	0.42	0.42	0.42
XS1351517260	-1.32	-1.32	-0.63	-0.63
XS1367225577	1.93	1.93	1.93	1.93
XS1367226385	-1.20	-1.20	-1.17	-1.17
XS1367226468	-0.04	-0.04	-0.04	-0.04
XS1367227359	-0.16	-0.16	-0.14	-0.14
XS1379598284	0.44	0.44	0.44	0.44
XS1383831648	-0.05	-0.05	-0.05	-0.05
XS1383852057	-0.44	-0.44	-0.44	-0.44
XS1392102551	0.18	0.18	0.18	0.18
XS1401328965	-0.21	-0.21	-0.20	-0.20
XS1402169848	-1.30	-1.30	-1.06	-1.06
XS1412393172	-0.29	-0.29	-0.27	-0.27
XS1414146669	-0.01	-0.01	-0.02	-0.02
XS1417410989	1.70	1.70	1.67	1.67
XS1418779929	-1.79	-1.79	-1.55	-1.55
XS1422841202	0.00	0.00	0.00	0.00
XS1432564133	-1.54	-1.54	-1.51	-1.51
XS1436518606	-0.01	-0.01	-0.01	-0.01
XS1437622548	-0.04	-0.04	-0.05	-0.05
XS1437622977	-0.18	-0.18	-0.18	-0.18
XS1437844100	-0.03	-0.03	-0.04	-0.04
XS1490726590	0.00	0.00	0.01	0.01
XS1493432295	-0.49	-0.49	-0.52	-0.52
XS1500337644	-0.06	-0.06	-0.04	-0.04
XS1502438820	-0.09	-0.09	-0.08	-0.08
XS1508672828	-0.09	-0.09	-0.11	-0.11
XS1527753187	0.01	0.01	0.02	0.02

Table 24 – **Estimation of the green bond premium in step 1 regression.** This table presents the green bond premia estimated by performing FEGLS and FE regressions with ΔBA and ΔZTD controls. It can be seen here that in the case of a specific green bond, the differences in the premium between the four types of regressions are often very small.

		$\widehat{p}_i(\mathrm{BA})$ - All bonds, issued amount > USD 100m					
		(a)	(b)	(c)	(d)	(e)	(f)
ACF	Number of lags	0	0	0	0	0	0
Durbin Watson AR(1)	Statistic	2.17	2.13	2.13	2.15	2.13	2.16
	P Value	0.61	0.6	0.71	0.67	0.61	0.68
Breusch-Pagan	Statistic	9.39 (df=13)	7.22 (df=3)	5.87 (df=6)	7.4 (df=4)	7.14 (df=4)	6.08 (df=8)
	P Value	0.74	0.07	0.44	0.12	0.13	0.64
Multicolinearity	$\sqrt{\mathrm{GVIF}}$ Yield	2.36	1.02	1.11	1.04	1.06	1.19
	$\sqrt{\mathrm{GVIF}}$ Group	1.28	1.02	2.74	1.03	1.06	2.81
	$\sqrt{\mathrm{GVIF}}$ Currency	2.62					
	$\sqrt{\mathrm{GVIF}}$ Rating			2.85			3.01
	$\sqrt{\mathrm{GVIF}}$ Maturity				1.04		1.09
	$\sqrt{\mathrm{GVIF}}$ Issued Amnt.					1.09	1.09
	$\sqrt{\mathrm{GVIF}^{(1/(2\mathrm{Df}))}}$ Yield	1.54	1.01	1.06	1.02	1.03	1.09
	$\sqrt{\mathrm{GVIF}^{(1/(2\mathrm{Df}))}}$ Group	1.06	1.01	1.29	1.01	1.01	1.29
	$\sqrt{\mathrm{GVIF}^{(1/(2\mathrm{Df}))}}$ Currency	1.06					
	$\sqrt{\mathrm{GVIF}^{(1/(2\mathrm{Df}))}}$ Rating			1.73			1.20
	$\sqrt{\mathrm{GVIF}^{(1/(2\mathrm{Df}))}}$ Maturity				1.02		1.04
	$\sqrt{\mathrm{GVIF}^{(1/(2\mathrm{Df}))}}$ Issued Amnt.					1.04	1.05

Table 25 – **Tests of step 2 regression performed on all the bonds with an issued amount greater than USD 100 million.** This table presents the results of the tests performed using step 2 regression (specifications (a) to (f)) on the whole sample of bonds with an issued amount greater than USD 100 million. The tests do not bring to light any serial correlation or signs of heteroscedasticity. The level of multicolinearity is low.

		$\widehat{p_i}$(BA) - EUR bonds, issued amount > USD 100m								
		(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
ACF	Number of lags	1	1	0	0	0	0	0	0	0
Durbin Watson AR(1)	Statistic	1.04	1.02	1.51	1.49	1.91	1.62	1.69	1.99	1.71
	P Value	0.01	0.01	0.1	0.11	0.66	0.16	0.14	0.52	0.13
Breusch-Pagan	Statistic	0.21 (df=1)	0.92 (df=1)	1.98 (df=2)	4.42 (df=3)	6.08 (df=2)	7.14 (df=5)	5.82 (df=5)	7.98 (df=4)	8.35 (df=7)
	P Value	0.64	0.34	0.37	0.22	0.05	0.21	0.32	0.09	0.30
Multicolinearity	$\sqrt{\text{GVIF}}$ Rating						4	1.14		4.44
	$\sqrt{\text{GVIF}}$ Maturity									
	$\sqrt{\text{GVIF}}$ Maturity^2									
	$\sqrt{\text{GVIF}}$ Issued Amnt.			3.35				3.49	3.9	4.17
	$\sqrt{\text{GVIF}}$ Issued Amnt.^{2}			3.35				3.39	3.7	3.84
	$\sqrt{\text{GVIF}}$ Group						4		1.26	4.91
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Rating						1.26	1.02		1.28
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Maturity									
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Maturity^2									
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Issued Amnt.			1.83				1.87	1.98	2.04
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Issued Amnt.^{2}			1.83				1.84	1.92	1.96
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Group						1.41		1.06	1.48

Table 26 – **Tests of step 2 regression performed on EUR bonds with an issued amount greater than USD 100 million.** This table presents the results of the tests performed using step 2 regression (specifications (g) to (o)) on EUR bonds with an issued amount greater than USD 100 million. The tests do not show the existence of any serial correlation except for specifications (g) and (h). There are no signs of heteroscedasticity and the level of multicolinearity is low.

		$\widehat{p}_i$(BA) - USD bonds, issued amount > USD 100m								
		(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)	(x)
ACF	Number of lags	0	0	0	0	0	0	0	0	0
Durbin Watson AR(1)	Statistic	2.01	1.94	1.85	1.92	2.07	2.05	2.13	2.11	2.30
	P Value	0.85	0.81	0.53	0.77	0.85	0.91	0.77	0.79	0.41
Breusch-Pagan	Statistic	0.01 (df=1)	0.09 (df=1)	1.05 (df=1)	4.52 (df=3)	4.95 (df=1)	3.13 (df=2)	3.88 (df=4)	5.85 (df=2)	4.20 (df=5)
	P Value	0.94	0.77	0.31	0.21	0.03	0.21	0.42	0.05	0.52
Multicolinearity	$\sqrt{\text{GVIF}}$ Yield						1.15	1.81	1.72	2.19
	$\sqrt{\text{GVIF}}$ Rating							1.81		5.63
	$\sqrt{\text{GVIF}}$ Maturity									
	$\sqrt{\text{GVIF}}$ Issued Amnt.									
	$\sqrt{\text{GVIF}}$ Group						1.15		1.72	3.59
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Yield						1.07	1.35	1.31	1.48
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Rating									1.33
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Maturity									
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Issued Amnt.									
	$\sqrt{\text{GVIF}^{(1/(2\text{Df}))}}$ Group						1.07	1.10	1.31	1.89

Table 27 – **Tests of step 2 regression performed on USD bonds with an issued amount greater than USD 100 million.** This table gives the results of the tests performed using step 2 regression (specifications (p) to (x)) on USD bonds with an issued amount greater than USD 100 million. The tests do not show the existence of any serial correlation. There are no signs of heteroscedasticity, except for specification (t) and the level of multicolinearity is low.