The Added Value of Green Bonds

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Author:

Ellis Piva

Candidate number:

453317

Supervisor:

Laurens Swinkels

Second Assessor:

Xintong Zhan

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Erasmus School of Economics

Erasmus University Rotterdam

ABSTRACT

Given the recent expansion of the green bond market as well as its crucial role in reducing the risks associated with climate change, my research is aimed at investigating whether green bonds provide investors with an added value, in terms of return and diversification. First, I use a matching procedure to build a data sample of 112 green bonds, each matched with the most similar conventional bond available in the market. The yield differential between green and conventional bonds is slightly positive (6 bps), on average, and varies according to the market segment considered. Such premium is driven by the amount issued and credit rating of the green bond as well as by the median difference in modified duration between the green and the conventional bond. Secondly, I compare the characteristics and performance of three green bond indices available in the market, concluding that differences in their selection criteria and definition of "greenness" are likely to influence both their investment style and performance. Lastly, I use mean-variance spanning tests and mean-variance frontier analysis to evaluate the diversification properties of green bonds for US and international investors, whose portfolios already invest in conventional bonds and stocks. My results suggest that green bonds do not increase their portfolio diversification. I conclude that other factors, not related to the risk-return characteristics of such bonds, are likely to drive the growing investments in the green bond market.

Keywords: Green bonds, Bond indices, Fixed income, Sustainable finance, Asset management, Allocation

JEL Classification: C21, C22, G11, G12, Q59

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1. Introduction

In this days and age, one of the greatest threats for the world population is represented by climate change. According to IEA (2016), the energy sector is responsible for two-thirds of all greenhouse gas emissions as well as for 80 percent of carbon emissions. This highlights that the energetic infrastructures on which countries have relied over the past decades are no longer sustainable from an environmental perspective and, thus, radical transformations are needed to tackle climate change. The Conference of Parties (COP) 21, held in Paris in 2015, represented an important step in this direction. By signing the Paris Agreement, the representatives of 197 countries agreed to reduce their greenhouse gas emissions in the shortest timespan possible to keep global warming below 2 degrees Celsius. To meet this target and achieve a low-carbon economy, IEA (2014) estimates that USD 53 trillion in climate-aligned investments are required by 2035, even if critical progresses are to be achieved within the next decade. As a result, the fundamental question relates to how such investments should be financed.

In the last few years, many initiatives have been launched. To this extent, the global insurance industry, accounting for one third of the global investment capital, tripled its climate-smart investments in 2015 and committed to increase them tenfold by 2020 (United Nations (2015)). A similar initiative goes under the name "Portfolio Decarbonization Coalition". The latter counts 27 institutional investors who aim at decarbonizing USD 600 billion out of the USD 3.2 trillion assets under management. Furthermore, with the Paris Green Bond Statement (2015), asset owners, investment managers and individual funds managing a total of USD 11.2 trillion of assets agreed to work together in order to foster the expansion and development of the emerging green bond market. Della Croce et al. (2011) define green bonds as fixed-income securities issued by governments, multi-national banks and corporations in order to raise the necessary capital for a project which contributes to a low-carbon, climate resilient economy. As of July 2016, green bonds amounted to USD 118 billion, accounting for 17 percent of the wider climate-aligned bond universe (see CBI (2016) for a detailed review). Their issuance soared from USD 3 billion in 2012 to USD 81 billion in 2016. This trend was facilitated by the introduction of broad industry guidelines, called Green Bond Principles (GBP), which contributed in promoting both market integrity and transparency. Recently, these guidelines have been complemented with the CBI standards, which define specific criteria that a bond needs to meet in order to be labelled as "green".

Considering the recent growth of the green bond market as well as its crucial role in reducing the risks associated with climate change, the main question that I want to address here is whether green bonds can add value to investors' portfolio, from both a return and diversification perspective.

To this extent, the contribution of my paper is twofold. First, I conduct a bond-level analysis aimed at understanding whether green bonds provide investors with a yield that, on average, is different than that offered by comparable conventional bonds. To do that, I use a matching procedure to construct a data sample containing 112 investment grade senior green bonds, each matched with its most similar conventional (non-green) bond available in the market. The analysis begins by testing the magnitude and significance of the yield differential for several segments of the green bond market, where the latter are defined according to bonds' characteristics. Given that such market has a global coverage, my analysis provides useful insights on which segments are likely to offer the best return perspectives. After that, I focus on the determinants of the yield spread in order to identify which factors affect the attractiveness of green bonds. To complement my study and extend the scope of my research question, I conduct an index-level analysis by considering three green bond indices (GBI) available in the market: the Bloomberg Barclays Global GBI, the Standards & Poor's GBI and the Bank of America Merrill Lynch GBI. After documenting their characteristics and past performance, I implement a return-based style analysis aimed at investigating whether they reflect a particular investment style. As a last step, I use mean-variance spanning tests and mean-variance frontier analysis to evaluate the diversification opportunities that green bonds offer to both US and international investors, who already invest in bond and equity markets. To my knowledge, this is the first study that evaluates the investment styles and diversification properties of green bond indices.

My results indicate that the yield differential between green and conventional bonds amounts to 6 bps, on average, suggesting the existence of a slightly positive premium related to green bond investments. However, such value varies according to the market segment considered. To give an example, the average yield differential is small and negative in the case of bonds issued by government-related entities (-3 bps), whereas it becomes positive and significant when considering issuers in the financial sector (21 bps). Furthermore, the analysis points out that the latter depends on the amount issued and credit rating of the green bond, as well as on the spread in modified duration between the green and the conventional bond. Hence, when investing in this subset of the fixed-income market, investors should be aware of the fact that the return prospects change according to both bond's characteristics and market segments.

With regard to the analysis at the index level, I find that green bond indices differ in their definition of "greenness" and in the criteria considered for bonds' selection. Such differences are likely to influence both their investment styles and performance. The results of both mean-variance spanning tests and mean-variance frontier analysis indicate that green bonds do not provide investors with significant diversification opportunities, when their base-case portfolio is highly diversified. Similarly, in the case of a US investor that hedges currency risk when investing in the global green bond market, such diversification benefits are positive but limited. On the other hand, we cannot generalize such findings to all classes of investors because of the specific assumptions made on the composition of investors' base-case portfolios.

All things considered, green bonds do not seem to have return and diversification properties that are different from those of similar conventional bonds. As a result, the growing interest of institutional and retail investors in the green bond market should stem from other factors as well. In the case of large institutional investors, such as pension funds and insurance companies, a key role is likely played by ESG policies and reputational reasons. Furthermore, another element that is driving the commitment of such investors is the increasing awareness regarding environmental risks and the effects of climate change. Despite being still at an early stage, I expect academic research on the green bond market to develop rapidly in the next future, considering the above-mentioned trends and the crucial role that such market plays in tackling climate change.

2. Literature review

Many authors address the characteristics and performance of green investing. Among these, Inderst et al. (2012) summarize the existing definitions of green investments and measure their implications for the asset allocation of institutional investors. They find that such investments differ in magnitude by asset class. Traditionally, they applied most to equities, with only a marginal relevance for bonds, real estate and alternative asset classes. As a consequence, most of the literature in the area of green investing focused around the effects of firms' social and environmental performance on stock prices. To this extent, many empirical studies agree on the existence of a positive relationship between firms' responsible investing and portfolio performance. For instance, Derwall et al (2005) highlight the benefits for investors of considering environmental criteria in their investment selection process. After accounting for common risk factors and transaction costs, they find that an eco-efficient stock portfolio substantially outperformed a less eco-efficient one over the period 1995-2003. In a similar study, Statman and Glushkov (2009) argue that socially responsible investors gain an advantage over conventional investors by concentrating their investments in the stocks of companies with high levels of social responsibility. What emerges from these academic studies is that, when including environmental and social criteria in their investment process, stock market investors are likely to increase their portfolios return, on average.

Concerning the fixed income market, there are some fundamental differences with the equity market that make the above considerations not directly applicable. Contrarian to stockholders, bondholders are interested in financial tools that provide a constant and predictable stream of cash flows with a lower level of embedded risks. Indeed, bonds not only have a privileged claim on a firm's assets in case of default, but they are also characterized by lower market volatility than stocks. With regard to the payoff structure of a corporate bondholder, this is substantially different from that of a stockholder and, as showed by Merton (1973), it can be replicated by purchasing one stock of the firm and selling one call option on the same stock. This results in bonds being characterized by a limited upside potential and a downside risk of 100 percent. Given such differences and considering that green investing has always been a prerogative of other asset classes, it is not surprising that the number of academic studies regarding the green bond market has been very limited so far. Furthermore, the development of literature in the field is further complicated by the fast-changing dynamics of green bonds' supply and demand as well as by the lack of a comprehensive and reliable regulation of the market. A preliminary analysis is provided by the OECD (2015), which states that the financial features of green bonds are identical to those of similar conventional bonds from the same issuer. These include, among others, the credit quality of the bond and the yield at the issue date. On the supply side, the motivation underlying this "flat-pricing" is that investors are unwilling to pay a premium to "go green". Not being able to realize pricing advantages, the most common reason for corporate issuers to issue green bonds is expanding the investor pool by offering a product that satisfies investor's demand for sustainable fixed income securities, according to BNEF (2014). Similarly, on the demand side, investors have not been able to require a higher return from investing in green bonds because the underlying risks are not different from those of similar conventional bonds. Barclays (2015) uses a sample consisting of the Global Credit Index to run a regression on credit spreads in order to quantify differences in yields between green and conventional bonds. After accounting for other market risk factors, they find that green bonds trade at 17 bps lower in option-adjusted spread (OAS) compared to similar non-green bonds. However, they do not provide a straightforward reason for this difference in yields, leaving alternative explanations open for discussion. Their main concern relates to the fact that such premium may result from a mismatch between supply and demand, which is likely due to investors' oversubscription in a market characterized by limited green bond supply. Thus, a more balanced market is likely to reduce the temporary yield differential with investors moving towards cheaper investments. Another explanation is that green bonds may be characterized by a lower market volatility which then justifies, according to the traditional risk-return relationship, their lower yield. This is the case when trading volume is relatively low due to a predominance of long-term environment-focused investors, which results in greater price stability.

One of the most recent contributions to the literature on the green bond market is the work of Zerbib (2017), which considers a global database of 135 green bonds to test both the existence and the determinants of a premium inherent to such securities. For each green bond, the author uses a matching method to select the two most similar conventional bonds and construct a synthetic non-green bond that matches its characteristics. After controlling for the effects of liquidity, he finds that the green bond premium is slightly negative (-2 bps), on average. Furthermore, bonds with lower ratings and lower amount issued tend to have a greater negative premium and, therefore, tend to be more expensive for investors if compared to equivalent conventional bonds. Considering such findings, he argues that regulatory and fiscal measures must be adopted to provide investors with the right incentives and, at the same time, foster the growth of the green bond market. One of the main limitations, stated by the author, is related to the quality of data. The bond yield may, in fact, not reflect the fair value of a bond in the case the latter is not frequently traded. A second limitation, linked to the previous one, stems from the use of the bid-ask spread to measure and remove the effect of liquidity from the yield differential between green and conventional bonds. To this extent, Helwege et al. (2014), argue that many liquidity proxies require information on bonds' prices, which is often not available due to their low trading frequency. Bonds are, indeed, very unlikely to trade if they are purchased by buy and hold investors, such as pension funds or insurance companies. As suggested by Sarig and Warga (1989), the fraction of a particular bond issue that has been absorbed into the inactive portfolios of such investors tend to increase over time, hence bonds tend to become less liquid as they approach maturity. As far as the green bond market is concerned, these considerations become of greater importance, given the relevant role played by long-term institutional investors and the average tenure of green bonds, which ranges from 5 to 10 years (CBI (2016)). Related to this, Garbade and Silber (1976) suggest that processing data basing on the magnitude of the bid-ask spread does not perform equally in each period considered. In fact, traders are likely to use larger spreads in more volatile periods, given the higher uncertainty associated with the price of illiquid bonds. Differences with the work of Barclays (2015) and Zerbib (2017) are further discussed in the section presenting the results of my analysis at the bond level.

Concerning the analysis on green bond indices, no academic study on the characteristics and performance of such indices has ever been published so far, to my knowledge. As a consequence, the results of my analysis at the index level are the first of their kind.

3. Data description

3.1 Green bonds data

Data on green bonds complying with the Green Bond Principles is obtained from Bloomberg. I consider all green bonds, both active and matured, issued before December 30, 2016. After removing all bonds whose amount issued is lower than USD 1 million and those with missing values on maturity date, ISIN code and coupon rate, the data sample counts 766 green bonds. To obtain the most similar conventional bond for each green bond considered, I employ a matching procedure. More precisely, I search for conventional bonds having exactly the same issuer, currency, rating[1], seniority and term to maturity (at issue), where the latter

[1] The process followed to identify each bond's credit rating consists of 3 steps: first, the Bloomberg Barclays Composite Rating is used. The latter is a blend of a security's Moody's, S&P, Fitch, and DBRS ratings. The rating agencies are evenly weighted and it is calculated by taking the average of the existing ratings, rounded down to the lower rating in case the composite is between two ratings. Secondly, given that a composite rating is not generated if the bond is rated by only one of the four rating agencies, I consider the rating even if provided only by one rating agency. Lastly, in case the previous steps prove not to be successful, the rating of the issuer on senior unsecured debt is used as a reliable proxy of the bond's rating.

is expressed in years and rounded up to the closest integer number. With the last criteria, the tenure of the green bond may diverge from that of the conventional bond by six months at most. My choice of focusing on such variable builds on the considerations made by Houweling et al (2005), who suggest that a bond's age can be used as a proxy for its liquidity. Furthermore, to maximize the overlapping between the daily time series of their yield to maturity and reduce the potential biases related to bonds' maturity, I consider as a candidate for matching only the conventional bond whose issue date is closest to that of the green bond. To give an example, if two bonds have the same term to maturity (at issue) and their issue dates are three months far from each other, then also their maturity dates will differ by three months. With this approach, I reduce the likelihood of comparing long-term bonds that are approaching maturity with short-term bonds that have been issued recently, in case they both have the same residual term to maturity. Thus, I reduce significantly the liquidity premium incorporated in the yield of older bonds because, as indicated by Sarig and Warga (1989), bonds tend to become less liquid as they approach maturity. However, it is worth noting that such mismatch is not completely removed as it is rare to find two bonds (green and conventional) having exactly the same issue date. Aware of the fact that this may influence the results of my analysis on the yield differential, I test for this eventuality by analysing the distribution of such variable for pairs characterized by shorter and larger differences in maturity dates.

Among the 423 pairs of bonds resulting from this matching procedure, data on the performance of both bonds is found only for 191 pairs, thus reducing the size of the data sample by 55 percent. The daily time series of the annualized yield to maturity and modified duration for both green and conventional bonds are obtained from Thomson Reuters Financial Datastream. The former is based on the Datastream default price and calculates the yield as if annual coupons are paid, thus it makes bonds with different coupon frequencies comparable to bonds with annual coupons. The last day considered in the performance-matching procedure is June 30, 2017. After excluding those bonds that are non-senior (8 pairs), high yield (6 pairs), non-rated (21 pairs) or for which the two ratings are different (6 pairs), I also remove those pairs for which the amount issued of the two bonds is different by a factor greater than five (41 pairs). The last step allows me to control for further differences in liquidity, as indicated by Houweling et al (2005) and Bao et al. (2011). Note that the overall number of pairs excluded equals 73, because such bonds may present more than one characteristic qualifying for exclusion. Thus, I focus on the remaining 118 investment grade senior green bonds, each matched with its closest conventional bond. The construction of the dataset continues with the definition of a performance variable, the daily difference in the yield to maturity between green and conventional bonds, which is defined as:

$$\Delta y_{i,t} = y_{i,t}^{GB} - y_{i,t}^{CB}$$

where $y_{i,t}^{GB}$ and $y_{i,t}^{CB}$ are the daily yields to maturity of the green and conventional bond respectively. I will refer to $\Delta y_{i,t}$ also as the "daily yield differential". The same variable, in relative terms, is defined as:

$$\Delta\% y_{i,t} = \frac{y_{i,t}^{GB} - y_{i,t}^{CB}}{\left|y_{i,t}^{CB}\right|}$$

where the denominator $\left|y_{i,t}^{CB}\right|$ is the absolute value of the daily yield to maturity of the conventional bond, necessary to maintain the partial order in the case of negative yields. Similarly, I calculate the daily difference in modified duration between the two bonds:

$$\Delta m_{i,t} = m_{i,t}^{GB} - m_{i,t}^{CB}$$

where $m_{i,t}^{GB}$ and $m_{i,t}^{CB}$ are the modified durations of the green and conventional bond respectively. To reduce the effect of spurious outliers on the panel dataset and make the following analysis more robust, I employ a 95 percent winsorization on the average value of the percentage difference in yield to maturity (*Average* $\Delta\% y_i$). With this adjustment, I remove four pairs of bonds, two on each side of the distribution. In addition, other two pairs are excluded because of their anomalous value in the median difference in yield to maturity (*Median* Δy_i). Given the high level of matching existing between green and conventional bond for both pairs, such difference remains unexplained and justifies their exclusion. The two pairs are presented in Table A (Appendix). As a result, the final dataset counts 112 green bonds for a total of 49,154 observations. A list of these bonds, including a description of their characteristics, is provided in Table I (Appendix).

The approach just described allows me to test for the existence and significance of a yield differential between green and conventional bonds, which is largely due to their different nature. Indeed, the effect of other common factors is removed and discrepancies between bonds' characteristics are minimized. Seven examples of high-quality matching are shown in Table 1. For each of these pairs, the characteristics of interest of the two bonds are identical apart from small differences in coupon rate and maturity date. Yet, the (median) yield differential ranges from -15 bps to 35 bps and, thus, highlights the importance of analysing its distribution within different segments of the green bond market.

The main trade-off faced in the construction of the dataset is that between the number of lost observations and the number of constraints imposed on the dataset. To give an example, the inclusion of one further constraint on the coupon type would remove 18 pairs of bonds from the analysis. As a result, I choose not to impose such constraint and, as a robustness check, I separately analyse the distribution of performance statistics for both fixed-rate and floating-rate bonds. It turns out that the two subsets have approximately the same distribution and, thus, the overall results are not affected by the inclusion of floating-rate bonds. In the following section, I describe the composition of the final dataset counting 112 green bonds.

Table 1 – Examples of high-quality matching

This table contains 7 examples of high-quality matching between green and conventional bonds obtained from the matching procedure used to build the data sample counting 112 pairs. The first column shows name, ticker, country and market sector (BICS1) of the issuer. Type equals "G" in the case of green bonds and "C" in the case of conventional bonds. "Mat (Years)" represents the term to maturity in years (at issue). "Amt (LC)" is the amount issued expressed in local currency (millions). "Cpn Freq" indicates the coupon frequency. "Med. ytm" and "Med. $\Delta y_{i,t}$" indicate the median yield to maturity and the median difference in yield to maturity.

Issuer	Type	Curr	ISIN Bond Ticker	Issue Date	Mat Date	Mat (Years)	Amt (LC)	Cpn (%)	Cpn Freq.	Cpn Type	Payment Rank	Rating	Med. ytm	Med. $\Delta y_{i,t}$
Name: NRW Bank Ticker: NRWBK Country: Germany BICS1: Government	**G**	EUR	DE000NWB0AB2	11/4/2014	11/5/2018	4	500.0	0.25%	1	Fixed	Sr Uns.	AA	-0.25	0.02
	C	EUR	DE000NWB16X8	7/23/2014	7/23/2018	4	500.0	0.50%	1	Fixed	Sr Uns.	AA	-0.24	
Name: City of Oslo Norway Ticker: OSLO Country: Norway BICS1: Government	**G**	NOK	NO0010752702	12/4/2015	9/4/2024	9	1,500.0	2.35%	1	Fixed	Sr Uns.	AAA	2.18	0.08
	C	NOK	NO0010727829	12/11/2014	3/14/2024	9	1,500.0	2.30%	1	Fixed	Sr Uns.	AAA	2.14	
Name: Stangastaden AB Ticker: STANAB Country: Sweden BICS1: Financials	**G**	SEK	SE0007490750	9/9/2015	9/9/2020	5	500.0	0.21%	4	Float	Sr Uns.	AA	0.29	0.35
	C	SEK	SE0006453114	11/25/2014	11/25/2019	5	500.0	0.43%	4	Float	Sr Uns.	AA	-0.10	
Name: Regency Centers LP Ticker: REG Country: United States BICS1: Financials	**G**	USD	US75884RAT05	5/16/2014	6/15/2024	10	250.0	3.75%	2	Fixed	Sr Uns.	BBB	3.49	-0.15
	C	USD	US75884RAU77	8/17/2015	11/1/2025	10	250.0	3.90%	2	Fixed	Sr Uns.	BBB	3.65	
Name: Unibail-Rodamco SE Ticker: ULFP Country: France BICS1: Financials	**G**	EUR	XS1218319702	4/15/2015	3/14/2025	10	500.0	1.00%	1	Fixed	Sr Uns.	A	0.98	-0.14
	C	EUR	XS1376614118	3/9/2016	3/9/2026	10	500.0	1.38%	1	Fixed	Sr Uns.	A	1.11	
Name: Link Finance Cayman Ticker: LINREI Country: Cayman Islands BICS1: Financials	**G**	USD	XS1453462076	7/21/2016	7/21/2026	10	500.0	2.88%	2	Fixed	Sr Uns.	A	3.40	0.18
	C	USD	XS1105268228	9/3/2014	9/3/2024	10	500.0	3.60%	2	Fixed	Sr Uns.	A	3.23	
Name: Southern Power Co Ticker: SO Country: United States BICS1: Utilities	**G**	USD	US843646AN06	11/17/2015	12/1/2017	2	500.0	1.85%	2	Fixed	Sr Uns.	BBB	1.49	-0.08
	C	USD	US842587CN56	5/24/2016	7/1/2018	2	500.0	1.55%	2	Fixed	Sr Uns.	BBB	1.73	

3.2 Descriptive statistics

In this section, I focus on the distribution of green bonds according to market sector, issuer's country classification, currency of issue, credit rating, term to maturity (at issue) and amount issued. The total amount issued of the green bonds considered is approximately USD 40.74 billion. Note that this figure does not represent the total amount outstanding of such bonds at the end of 2016, because 20 out of the 112 bonds matured before December 30, 2016. These bonds account for a total of USD 3.17 billion, representing less than 8% of the total USD volume of the dataset[2].

Table 2 – Distribution of green bonds by BICS1 and country classification

Panel (a) provides information on the distribution of the 112 green bonds considered in the data sample according to the first level of the Bloomberg Industry Classification System (BICS1), which classifies the industry sector of the issuer. Panel (b) provides information on such distribution according to the issuer's country classification. The issuer could belong to either a "Developed" or "Developing" country or, alternatively, be classified as a "Supranational Authority". Each panel shows data on the number, total amount and average amount of the green bonds issued. The first two are presented both in absolute and relative values. The amounts are expressed in USD millions.

(a) By BICS1	**USD mn**	**%**	**N°**	**%**	**Mean**
Government	25,249.4	62.0	73	65.2	345.9
Financials	7,617.5	18.7	28	25.0	272.1
Utilities	5,260.5	12.9	7	6.3	751.5
Technology	1,800.0	4.4	2	1.8	900.0
Consumer Discretionary	500.0	1.2	1	0.9	500.0
Industrials	315.6	0.8	1	0.9	315.6
Total	40,742.9		112		
(b) Country classification	**USD mn**	**%**	**N°**	**%**	**Mean**
Developed Country	23,426.0	57.5	63	56.3	371.8
Supranational Authority	14,516.9	35.6	43	38.4	337.6
Developing Country	2,800.0	6.9	6	5.4	466.7
Total	40,742.9		112		

Table 2 provides information on the distribution of green bonds with regard to the first level of the Bloomberg Industry Classification System[3] (BICS1) and the issuer's country classification. Concerning the former, Panel (a) shows that more than 60 percent of such bonds are issued by government-related

[2] The issued amount for bonds whose currency of issue was not the US Dollar was determined using the exchange rate of their currency against the US Dollars, as of December 30, 2016. Data is collected from Bloomberg.
[3] The Bloomberg Industry Classification System (BICS) is an industry classification system developed and maintained by Bloomberg that classifies securities based on business, economic function, and other characteristics. The first level (BICS1) of such system, called "Sector", is the broadest classification and represents general business activities.

institutions[4]. The second main issuer is represented by entities in the financial industry, which account for about 19 percent (USD 7.62 billion) of the total amount issued. The remainder is divided among corporate issuers belonging to different industry sectors, namely "Utilies", "Technology", "Consumer Discretionary" and "Industrials". It is interesting to note how their average amount issued, especially in the case of "Utilities" (7 bonds), is significantly greater than that of "Government" and "Financials" issuers. To this extent, the dataset is in line with the information provided by CBI (2016), which argues that a dominant role in the green bond market has traditionally been played by development banks (comprised in the category "Government") and, only recently, by commercial banks and corporate issuers.

Alternatively, a green bond issuer could be classified as a supranational authority or as belonging to either a developed or developing country[5]. The distribution of green bonds according to this classification is showed in Panel (b). It emerges that almost 58 percent (USD 23.43 billion) of the total amount is issued within developed countries and a further 36 percent (USD 14.52 billion) is issued by supranational authorities. The remaining 7 percent is issued within developing countries and highlights the marginal role of such category in my data sample. To give an example, the latter does not capture the dominant role of Chinese issuers in 2016, in which they accounted for more than one quarter of the total amount issued (CBI (2016)). As data on performance is not available for Chinese green bonds, these were automatically excluded during the matching procedure. Detailed information on the countries and institutions belonging to the three aforementioned types of issuers is provided in Table 3. Panel (a) shows that, among developed countries, the largest issuers are France, the Netherlands and Germany which account together for more than 60 percent (USD 14.68 billion) of the total USD volume of the green bonds considered. The three core countries of the European Union are followed by the United States, Norway and Sweden that, together, make up another 34 percent (USD 8.03 billion). Regarding the USD 2.80 billion issued by developing countries, it is worth noting that the limited number of bonds considered for each country does not allow for reliable considerations on a country level, when analysing the results on performance. The same is true for Japan and Australia, within developed countries. With regard to "Supranational Authorities", analysed in Panel (c), the principal issuer of green bonds in the data sample is the European Investment Bank (EIB) with USD 9.47 billion, followed by the International Bank for Reconstruction and Development (IBRD) with USD 2.32 billion. Together they account for more than 80 percent of the amount issued by such category, hence they could be considered as its main drivers.

[4] The label "Government" includes governmental authorities, government-related agencies and municipalities.

[5] While issuers belonging to the category "Supranational Authorities" were automatically identified by the Bloomberg Terminal from the field "Country of the Issuer", the others were classified as belonging to either "Developed" or "Developing" countries using information collected on the "Country Classification" section of the "World Economic Situation and Prospects 2014" (United Nations).

Table 3 – Distribution of green bonds by category and country of the issuer

Panels (a) and (b) contain information on the distribution of the green bonds considered in the data sample according to the country of their issuer, which could be classified as either "Developed" or "Developing". With regard to the category "Supranational Authorities", Panel (c) provides directly the name of the issuers, as they do not belong to any particular country. Each panel shows data on the number, total amount and average amount of the green bonds issued. The first two are presented both in absolute and relative values. The amounts are expressed in USD millions.

(a) Developed Countries	**USD mn**	**%**	**N°**	**%**	**Mean**
France	6,101.4	26.0	8	12.7	762.7
Netherlands	4,545.5	19.4	7	11.1	649.4
Germany	4,033.4	17.2	5	7.9	806.7
United States	3,850.0	16.4	6	9.5	641.7
Norway	2,266.0	9.7	10	15.9	226.6
Sweden	1,913.6	8.2	25	39.7	76.5
Japan	500.0	2.1	1	1.6	500.0
Australia	216.0	0.9	1	1.6	216.0
Total	23,425.9		63		
(b) Developing Countries	**USD mn**	**%**	**N°**	**%**	**Mean**
India	1,500.0	53.6	3	50.0	500.0
Cayman Islands	800.0	28.6	2	33.3	400.0
South Korea	500.0	17.9	1	16.7	500.0
Total	2,800.0		6		
(c) Supranational Authorities	**USD mn**	**%**	**N°**	**%**	**Mean**
European Investment Bank	9,469.7	65.2	14	32.6	676
International Bank for R&D	2,315.1	15.9	12	27.9	193
Asian Development Bank	1,163.3	8.0	4	9.3	291
African Development Bank	1,103.6	7.6	4	9.3	276
Nordic Investment Bank	329.4	2.3	4	9.3	82
European Bank for R&D	135.7	0.9	5	11.6	27
Total	14,516.9		43		

This is in line with the findings of CBI (2016) for what concern the dominant role of development banks as issuers of green bonds. To this extent, the European Investment Bank (EIB) has been the largest issuer up to the end of 2016, with a total amount issued of USD 17 billion. As a result, my data sample perfectly captures the role of supranational authorities, whose issuance makes up about 36 percent of the total amount issued of green bonds.

Table 4 – Distribution of green bonds by currency, rating, tenure and amount issued

This table provides information on the distribution of the 112 green bonds considered in the data sample according to four fundamental features: currency of issue, credit rating, term to maturity (at issue) and amount issued. Panel (a) contains statistics relative to the currency distribution. The category "Others" includes 7 green bonds, whose currencies of issue are Norwegian Krone (1 bond), Mexican Pesos (1 bond), Turkish Lira (3 bonds), Indonesian Rupiah (1 bond) and Indian Rupee (1 bond). The latter are not included because of their limited relevance. Panel (b) groups green bonds according to their credit rating. The remaining two panels, (c) and (d), contain information on the distribution of green bonds with regard to their term to maturity (at issue) and amount issued (expressed in US Dollars). Each panel shows data on the number, total amount and average amount of the green bonds issued. The first two are presented both in absolute and relative values. The amounts are expressed in USD millions.

(a) Currency of issue	**USD mn**	**%**	**N°**	**%**	**Mean**
EUR	16,957.7	41.6	21	18.8	807.5
USD	14,210.0	34.9	27	24.1	526.3
GBP	3,456.4	8.5	2	1.8	1728.2
SEK	2,937.6	7.2	34	30.4	86.4
CAD	1,488.0	3.7	4	3.6	372.0
AUD	918.6	2.3	9	8.0	102.1
BRL	203.2	0.5	4	3.6	50.8
ZAR	178.5	0.4	4	3.6	44.6
Others	392.9	0.9	7	6.3	56.1
Total	40,742.9		112		
(b) Credit Rating	**USD mn**	**%**	**N°**	**%**	**Mean**
AAA	21,184.8	52.0	60	53.6	353.1
A	7,878.3	19.3	17	15.2	463.4
AA	5,867.9	14.4	22	19.6	266.7
BBB	5,811.8	14.3	13	11.6	447.1
Total	40,742.9		112		
(c) Term to maturity (at issue)	**USD mn**	**%**	**N°**	**%**	**Mean**
Intermediate (5 to 12 years)	25,745.9	63.2	70	62.5	367.8
Short (less than 5 years)	9,403.8	23.1	33	29.5	285.0
Long (more than 12 years)	5,593.2	13.7	9	8.0	621.5
Total	40,742.9		112		
(d) Amount issued (USD)	**USD mn**	**%**	**N°**	**%**	**Mean**
[500 million, 1 billion]	17,253.3	42.3	31	27.7	557
More than 1 billion	15,423.4	37.9	10	8.9	1542
[100 million, 500 million]	6,254.9	15.4	26	23.2	241
Less than 100 million	1,811.2	4.4	45	40.2	40
Total	40,742.9		112		

Table 4 provides information on how green bonds are distributed with regard to their currency of issue, credit rating, term to maturity (at issue) and amount issued. It can be clearly seen from Panel (a) that the two main currencies of issue are the US Dollar and the Euro. Such currencies account for more than 75 percent (USD 31.17 billion) of the total amount issued, thus accurately reflecting the currency composition of the real green bond market. As suggested by CBI (2016), despite the still central role of the US Dollar and the Euro, the growing appetite of investors in the market is increasing the currency diversification of green bonds. For further information on the definition and statistics of the currencies considered in the dataset, see Tables B and C (Appendix). Regarding the credit rating of bonds, Panel (b) shows that 60 out of 112 bonds have a triple-A rating, which is primarily due to the dominant presence of large development banks and supranational authorities in the data sample. The remainder is almost equally divided between the other investment grade rating categories. Panel (c) highlights that more than 60 percent of green bonds have a tenure (at issue) of between 5 and 12 years, with the most common (45 bonds) being 5 years. The remainder is mainly concentrated around shorter maturities. The distribution is in line with that of the entire green bond market (CBI (2016)). The last panel of Table 4 shows that more than 40 percent of the bonds considered in the analysis have an issued amount below USD 100 million, whereas only 9 percent of them exceed USD 1 billion. Given that the average and median amount issued are USD 364 million and USD 227 million respectively, the distribution of green bonds with regard to such variable is negatively skewed.

Considering the statistics just presented, the dataset appears to be highly representative of the overall green bond market and, therefore, qualifies itself as a reliable proxy to test the hypothesis of whether investing in green bonds provide investors with an added value. In the following section, I describe the performance statistics of the 112 green bonds considered in the data sample.

3.3 Performance statistics

Starting from the unbalanced panel containing 49,154 observations, I calculate the median value of the annualized yield to maturity for both green and conventional bonds ($y_{i,t}^{GB}$ and $y_{i,t}^{CB}$). The median is computed also for the absolute and relative differences ($\Delta y_{i,t}$ and $\Delta\% y_{i,t}$) between the two yields. The choice of using the "median" to provide an indication of the absolute and relative performance of bonds is motivated by the fact that it is less subject than the "mean" to the effect of outliers, which are likely to be present when considering time series with a relatively high frequency. Given that these extreme observations are generally due to one-off events and tend to correct themselves within very-short time horizons, the "median" offers a more representative description of the overall performance of bonds. Table 5 contains the summary statistics describing the distribution of these median values for the entire data sample, as well as for four sub-categories: "Government", "Financials", "USD" and "EUR" bonds. Panel (a) provides the same statistics with regard to the length of the time horizon considered, expressed in days.

Table 5 – Summary statistics of performance variables

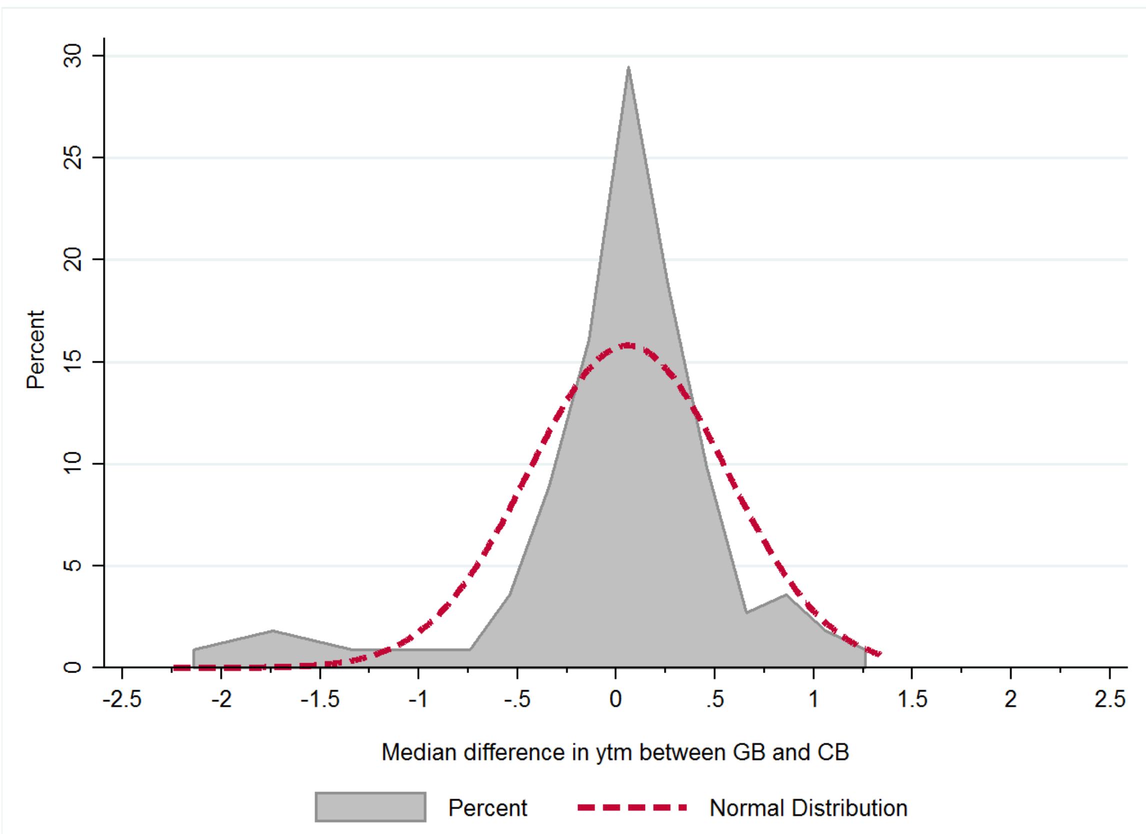
Panel (a) provides information on the length of the period for which the times series of bonds' performance are matched. The remaining panels contain the summary statistics relative to the distribution of the variable considered. Panels (b) and (c) consider the annualized yield to maturity of green (y_i^{GB}) and conventional bonds (y_i^{CB}), respectively. Panels (d) and (e) consider the absolute and percentage difference in yield to maturity between the two bonds, which are labelled as Δy_i and $\Delta\% y_i$. The statistics considered are: minimum value (Min), 25° percentile (P25), median, mean, 75° percentile (P75), maximum value (Max) and standard deviation (SD).

	Summary Statistics						
	Min	**P25**	**Median**	**Mean**	**P75**	**Max**	**SD**
(a) Number of Days							
All Bonds	35	201	344	439	608	1,392	277
BICS1: Government	35	195	410	479	695	1,392	306
BICS1: Financials	108	196	274	365	492	875	218
Currency: USD	108	212	291	339	491	679	158
Currency: EUR	170	278	446	501	734	930	261
(b) Median $y_i^{Green\ B.}$ (%)							
All Bonds	-0.25	0.48	1.32	2.25	2.80	12.6	2.83
BICS1: Government	-0.25	0.32	1.45	2.63	2.90	12.6	3.36
BICS1: Financials	0.18	0.41	1.10	1.41	1.96	3.49	1.13
Currency: USD	0.30	1.49	2.27	2.15	2.86	3.68	0.91
Currency: EUR	-0.25	0.09	0.81	0.72	1.21	1.73	0.62
(c) Median $y_i^{Conv\ B.}$ (%)							
All Bonds	-0.45	0.34	1.20	2.19	2.75	12.9	3.03
BICS1: Government	-0.45	0.07	1.33	2.67	3.09	12.9	3.58
BICS1: Financials	-0.18	0.45	0.81	1.20	1.63	3.65	1.17
Currency: USD	0.37	1.49	2.27	2.03	2.72	3.65	0.92
Currency: EUR	-0.38	-0.04	0.59	0.56	1.10	1.37	0.58
(d) Median Δy_i (%)							
All Bonds	-2.24	-0.10	0.07	0.06	0.29	1.33	0.50
BICS1: Government	-2.24	-0.15	0.02	-0.03	0.18	1.33	0.56
BICS1: Financials	-0.29	-0.08	0.17	0.21	0.33	1.11	0.36
Currency: USD	-0.33	-0.06	0.13	0.14	0.29	1.11	0.30
Currency: EUR	-0.49	0.00	0.14	0.17	0.31	0.92	0.32
(e) Median $\Delta\% y_i$							
All Bonds	-0.57	-0.05	0.05	0.37	0.30	5.70	0.90
BICS1: Government	-0.52	-0.06	0.01	0.25	0.19	3.45	0.73
BICS1: Financials	-0.57	-0.03	0.16	0.61	0.89	5.70	1.26
Currency: USD	-0.52	-0.04	0.05	0.09	0.19	1.24	0.30
Currency: EUR	-0.52	0.00	0.25	0.43	0.55	2.07	0.75

The average number of days for which bonds' performance is matched amounts to 439 days for the entire dataset, with a standard deviation of 277 days. By comparing the information contained in Panel (b) and (c), it emerges that the distribution of the median yield to maturity of green bonds ($Median\ y_i^{GB}$) is very close to that of conventional bonds ($Median\ y_i^{CB}$), thus highlighting the quality of the matching procedure used to build the data sample. Panel (d) contains the summary statistics relative to the distribution of the median difference in yield to maturity ($Median\ \Delta y_i$) which is also graphically represented in Figure 1. In the remainder of my study, I will refer to $Median\ \Delta y_i$ as the "yield differential".

Figure 1 – Distribution of the yield differential

The figure shows the distribution of the median difference in yield to maturity between green and conventional bonds ($Median\ \Delta y_i$) for the 112 pairs of bonds considered in the dataset (grey area). The dashed red line indicates which will be the theoretical normal distribution for the variable considered.



The latter is symmetric and concentrated around zero, with a mean of 6 bps and a median value of 7 bps[6]. This means that, on average, green bonds yield 6 bps more than their comparable conventional bonds.

[6] Note that it is not possible to infer the values contained in Panel (d) from those contained in Panels (b) and (c), because the median value of the difference in yield ($Median\ \Delta y_{i,t}$) is calculated on the time series of the differences and not as the difference between ($Median\ y_{i,t}^{GB}$) and ($Median\ y_{i,t}^{CB}$).

However, this is not the case when we consider the four subsamples separately. Indeed, Panel (c) shows that green bonds issued by government-related entities yield, on average, 3 bps less than their most similar conventional bonds. On the other hand, when the issuer is a financial entity, the average value of *Median* Δy_i is positive and amounts to 21 bps. Considering the other two subsamples, namely USD and EUR bonds, such average value has also a positive sign and amounts to 14 and 17 bps respectively. If we look at the median values we note that, for all subsamples, the magnitude of the yield differential decreases. In the case of government-related green bonds, it also changes sign, which suggests that the average value is driven by few negative observations. All things considered, the summary statistics suggest that the median difference in yield to maturity is positive, on average, for all subsamples. This is confirmed by the sign of the average value of the *Median* $\Delta\% y_i$, showed in Panel (d).

Given the heterogeneous composition of the dataset, I separately evaluate the performance statistics of smaller subsets of green bonds. As mentioned above when describing the steps followed for dataset construction, I do not impose any constraint on the coupon type. As a result, 17 out of 112 green bonds are floaters. Among these, 16 are issued within Sweden, indicating a relative preference of Swedish issuers for such bond's feature. Floating-rate green bonds are characterized by a distribution of the yield differential that is relatively more concentrated around zero, as suggested by the summary statistics shown in Table D (Appendix). Nevertheless, their inclusion does not affect the distribution of $Median\ \Delta y_i$ and $Median\ \Delta\% y_i$ for the entire dataset, which remains very similar to that obtained when considering fixed-rate bonds only.
Another aspect that is worth analysing relates to the distribution of the yield differential for pairs of bonds characterized by different distances in maturity dates. Figure A (Appendix) shows the distribution of such distances for both issue and maturity dates, whereas Figure B (Appendix) considers the distribution of $Median\ \Delta y_i$ when the distance in maturity dates is shorter than 36 and 6 months, respectively. It emerges that the distribution of the $Median\ \Delta y_i$ is slightly more concentrated around zero when considering the 38 bonds with a distance in maturity dates shorter than 6 months. The change in mean and median values amounts to 1 and 2 bps, respectively. However, after considering the trade-off faced when constructing the data sample, I conclude that the overall change in summary statistics does not justify the exclusion of 74 pairs of bonds. As a result, my analysis considers the entire data sample of 112 bonds, presented above.

4. The added value of green bonds

My approach, which is aimed at understanding whether green bonds add value to an investor's portfolio, is essentially twofold. In the first part I conduct a bond-level analysis, which focuses on determining the magnitude, significance and determinants of the yield differential between green and conventional bonds.

In doing that, I take into consideration several bond characteristics to provide information on how such yield spread changes when considering different subsamples of green bonds. In addition, I analyse the time series of the daily yield differential to assess its level of persistence over time. Concerning the second part, which consists of an index-level analysis, I focus on three green bond indices (GBI) available in the market: the Bloomberg Barclays Global GBI, the Standard & Poor's GBI and the Bank of America Merrill Lynch GBI. After documenting their characteristics and past performance, a style analysis is performed to investigate whether they reflect a specific investment style. As a last step, I use mean-variance spanning tests and mean-variance frontier analysis to evaluate the diversification properties of green bonds for the portfolios of both US and international investors, who already invest in conventional bonds and stocks.

4.1 Bond-level analysis

4.1.1 Magnitude and significance of the yield differential

The first step consists in dividing green bonds according to their features. The approach used here builds on the variables used to describe the distribution of green bonds in the dataset, which could be summarized as: market sector (BICS1), issuer's country classification, currency of issue, credit rating, term to maturity (at issue) and amount issued. Considering the dominant role of US Dollar and Euro as currencies of issue for green bonds, the following analysis is made also with regard to these two separate subsamples. In order to evaluate the significance of the yield differential between green and conventional bonds, I carry out a t-test on its average value for each of the subcategories considered. Such values is indicated as $Avg(M.\Delta y_i)$. Therefore, the null and alternative hypothesis are the following:

$$H_0\colon\ Avg(M.\Delta y_i) = 0$$

$$H_A\colon\ Avg(M.\Delta y_i) \neq 0$$

The alternative hypothesis (H_A) of a not-null average can be divided into two sub-hypotheses, separately testing for the significance of a positive and negative value of the argument.

$$H_{A1}\colon\ Avg(M.\Delta y_i) > 0$$

$$H_{A2}\colon\ Avg(M.\Delta y_i) < 0$$

The p-values are presented in Table 6, together with the corresponding value of the average yield differential. If the latter is positive then the reported p-value refers to H_{A1}. The opposite if true in the case of a negative value of $Avg(M.\Delta y_i)$. The first line of Table 6 contains the results of the t-test performed on the entire dataset and on the two currency subsamples already presented in Table 5.

Table 6 – Tests on the significance of the yield differential

This table contains the results of the t-tests on the average value of the median difference in yield to maturity between green and conventional bonds, with null hypothesis $Avg(M.\Delta y_i) = 0$. It considers first the entire datasample of 112 bonds and, then, USD and EUR bonds separately. Each panel, from (a) to (f), provides such results after dividing the bonds considered with regard to a specific bond feature. *The number of bonds presented in Panels (a) and (f) do not add up to the total of each sections because they consider only the most relevant subcategories for the two variables.

	All bonds			**USD bonds**			**EUR bonds**		
	N	**Average $(M.\Delta y_{i,t})$ in %**	**P-value**	**N**	**Average $(M.\Delta y_{i,t})$ in %**	**P-value**	**N**	**Average $(M.\Delta y_{i,t})$ in %**	**P-value**
All Bonds	112	0.06	0.11	27	0.14	0.01	21	0.17	0.01
(a) BICS1*									
Government	73	-0.03	0.33	13	0.06	0.21	12	0.06	0.26
Financials	28	0.21	0.00	9	0.31	0.01	3	0.07	0.30
Utilities	7	0.38	0.01	2	0.08	0.35	5	0.49	0.01
(b) Country classification									
Developed Countries	63	0.21	0.00	13	0.29	0.00	16	0.20	0.01
Supranational Authorities	43	-0.16	0.06	8	-0.04	0.26	5	0.10	0.31
Developing Countries	6	0.05	0.25	6	0.05	0.25	-	-	-
(c) Rating of the issue									
AAA	60	-0.07	0.17	12	0.06	0.21	7	0.10	0.23
AA	22	0.21	0.00	1	0.19	-	6	0.08	0.28
A	17	0.24	0.00	4	0.27	0.00	7	0.31	0.02
BBB	13	0.16	0.07	10	0.17	0.10	1	0.26	-
(d) Term to mat. (at issue)									
Short	33	-0.07	0.23	14	0.19	0.05	3	0.00	0.50
Intermediate	70	0.11	0.04	13	0.08	0.02	12	0.17	0.07
Long	9	0.12	0.17	-	-	-	6	0.26	0.02
(e) Amount issued									
< 100mn	45	-0.06	0.27	-	-	-	1	-0.49	-
[100mn, 500mn]	26	0.04	0.32	4	-0.09	0.23	5	0.19	0.07
[500mn, 1bn]	31	0.17	0.00	22	0.18	0.01	8	0.15	0.04
> 1bn	10	0.29	0.02	1	0.19	-	7	0.29	0.06
(f) Currency of issue*									
EUR	21	0.17	0.01						
USD	27	0.14	0.01						
SEK	34	0.21	0.00						
CAD	4	0.15	0.02						
AUD	9	-0.30	0.08						
BRL	4	0.01	0.49						
ZAR	4	-0.03	0.41						

Note that, while the positive value of $Avg(M.\Delta y_i)$ for USD (14 bps) and EUR bonds (17 bps) differs from zero with a 99% confidence level, for the entire dataset (6 bps) the confidence level is 89%. Thus, it is worth analysing separately different subcategories of green bonds to determine how the yield differential changes in magnitude and significance. Panel (a) of Table 6 contains the results of such tests with regard to the main sectors in which green bonds are issued. These are described by the first level of the BICS and include "Government", "Financials" and "Utilities". Regarding governmental issuers, the p-values suggest that the average yield differential is not statistically different from zero. On the other hand, green bonds issued within the sectors "Financials" and "Utilities" are characterized, on average, by a positive and significant yield differential. In the first case, such difference (21 bps) stems mainly from bonds denominated in US Dollars, whereas it is not significantly different from zero for EUR bonds. In the case of "Utilities" (38 bps), the opposite is true. However, the small size of the two currency-sector subsets does not allow for a generalization of the results.

Panel (b) considers variations in magnitude and significance of the average yield differential that depend on the issuer's country classification. Overall, green bonds whose issuers belong to a developed country have a yield differential of 21 bps, on average. In the case of USD and EUR bonds, such figure amounts to 29 and 20 bps, respectively. All values are significantly different from zero with a 99% confidence level. This is not the case for issuers classified as "Supranational Authorities" and those belonging to the group of developing countries, for which the average yield differential is not statistically different from zero. So far, these findings suggest that green bonds issued within developed countries provide investors with a yield differential that is higher than that provided by the other two categories. When we consider the entire data sample, green bonds issued by supranational authorities show an average yield differential that is negative (-16 bps) and significant with a 90% confidence level. This is partially explained by the fact that all 43 green bonds issued by "Supranational Authorities" have a triple-A credit rating, which highlights the low level of credit risk embedded in such bonds. In fact, the likelihood of a worsening in the creditworthiness of institutions like the EIB or the IBRD is very low. Furthermore, considering the predominant role that supranational issuers have had since market inception, a complementary explanation may be related to investors' oversubscription in a context where the initial supply of green bonds was limited. Indeed, when the demand exceeds significantly the supply, lower yields are likely to arise as a result of tighter pricing. This is often the case when a market is small in size and experiences high growth. According to Panel (b), the average yield differential for green bonds issued within developing countries is not statistically different from zero. However, we cannot generalize this finding to all green bonds whose issuer belongs to a developing country, given their scarce representation in my data sample.

Panel (c) and (d) contain information on the magnitude and significance of the average yield differential with regard to the credit rating and term to maturity (at issue) of the green bonds. If we look at the entire dataset, it emerges that such measure is negatively correlated with the credit rating of the bond and positively correlated with its initial tenure. Indeed, it ranges from -7 bps in the case of triple-A bonds to 16 bps in the case of triple-B ones, with a peak of 24 bps for bonds having a credit rating of single-A. On the other hand, short-term bonds show, on average, a yield differential of -7 bps whereas, for long-term bonds, such value amounts to 12 bps. The considerations made so far with regard to bonds' credit rating and tenure consider the entire data sample of 112 green bonds. Concerning USD and EUR subsamples, we note the existence of a similar relation but the low number of bonds considered is each sub-segment is likely to reduce the reliability of such considerations.

Panel (e) provides information on the positive relation existing between the average yield differential and bonds' issued amount, where the latter is expressed in US Dollars. Such relation is rather intuitive if we consider that higher issued amounts are usually associated with longer tenures and greater credit risks. Indeed, given the uncertainties surrounding both environmental risks and the projects aimed at countering them, green bonds are likely to compensate investors with a yield that is higher than that offered by similar conventional bonds. Lastly, Panel (f) analyses the results of the significance tests when green bonds are grouped according to their currency of issue. We note that the average yield differential is positive and significant for EUR, USD, SEK and CAD bonds, whereas it becomes negative (-30 bps) in the case of green bonds denominated in Australian Dollars (AUD). The median value is also negative and amounts to -6 bps. This is partially due to the fact that 8 out of 9 AUD bonds belong to the category "Government".

4.1.2 Determinants of the yield differential

In this section, I investigate the determinants of the yield differential ($Median\ \Delta y_i$) by performing nine linear regressions on the characteristics of the 112 green bonds considered in the data sample. For each bond, I consider its median yield to maturity ($Median\ y_i^{GB}$), the median difference in modified duration relative to the comparable conventional bond ($Median\ \Delta md_i$), its credit rating, term to maturity (at issue) and amount issued. Two sets of dummy variables are used to control for the effect of differences in market sector (BICS1) and currency of issue. The reference modalities are "Government" and "USD" respectively, thus the base case refers to USD green bonds issued by government-related entities.

Table 7 presents the results of such regressions and includes the last column of both Tables E1 and E2 (Appendix). The latter contain the results of the same set of regressions, performed on USD and EUR bonds separately. What emerges from regression (2) is that the $Median\ \Delta md_i$ has the greatest explanatory power among independent variables. As suggested by the value of the adjusted R-squared, such variable explains 13 percent of the variability of the yield differential and remains statistically significant at the 1% level also after adding other independent variables to the regression model. Panel (a) of Figure 2 depicts the relation

Table 7 – Results of the cross-sectional regressions on the yield differential

This table shows the results of the cross-sectional regression with dependent variable the median difference in ytm between green and conventional bonds ($Median\ \Delta y_i$). Nine regressions are performed. The last two columns contain the results of regression (7) of Table E1 and regression (8) of Table E2, both available in Appendix. The dependent variable ($Median\ \Delta y_i$), the green bond yield ($Median\ y_i^{GB}$) and the median difference in modified duration ($Median\ \Delta md_i$) are expressed as a percentage (e.g. 2% is indicated as 2). "Credit Rating" is a numerical variable ranging from 1 (AAA) to 4 (BBB). "Term to maturity" is the term to maturity at issue of the green bond (expressed in years). "Amount Issued" is the logarithm of the amount issued expressed in USD millions. "BICS1" and "Currency" are qualitative dummy variables containing 6 and 13 values respectively. Their reference modalities are "Government", for BICS1, and "US Dollar" for Currency. The complete model could be specified as follows:

$$Median\ \Delta y_i = \alpha + \beta_1 Median\ y_i^{GB} + \beta_2 Median\ \Delta md_i + \beta_3 Rating_i + \beta_4 Maturity_i + \beta_5 Amount\ Iss_i + \sum_{j=1}^{5} \beta_{5+j}\ BICS1_j + \sum_{k=1}^{12} \beta_{10+k}\ Curr_k + \varepsilon_i$$

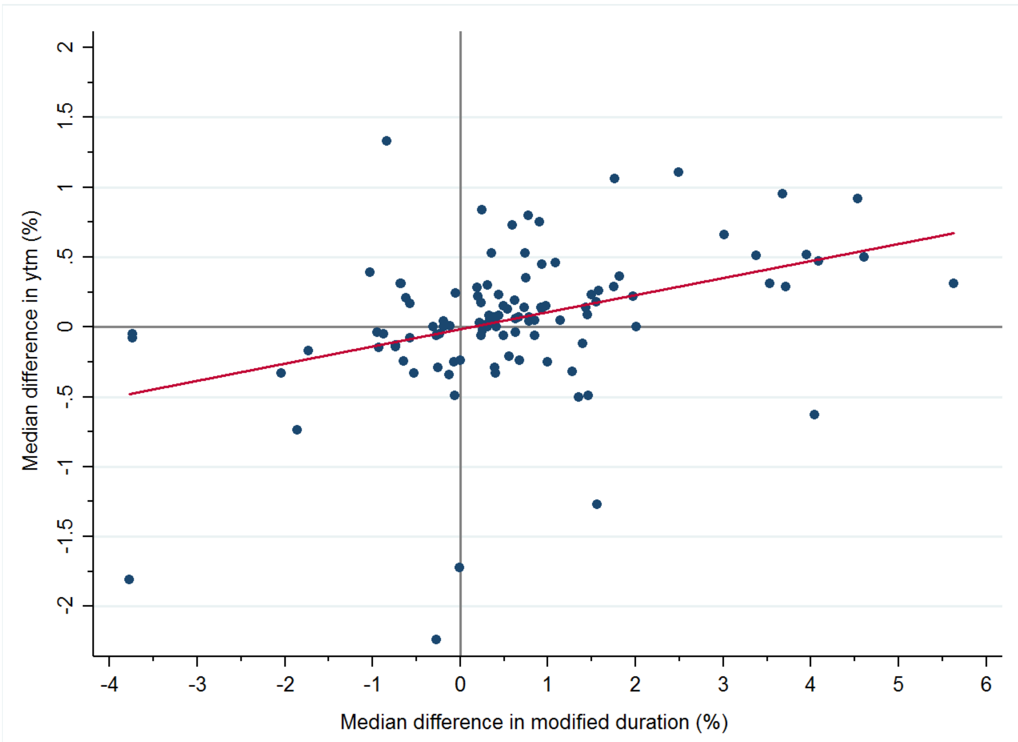
Dep: $Median\ \Delta y_i$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	USD bonds	EUR bonds
$Median\ y_i^{GB}$	-0.0498**		-0.0422								
	(0.0247)		(0.0255)								
$Median\ \Delta md_i$		0.122***	0.113***		0.116***			0.108***	0.0847***	0.192**	0.0796***
		(0.0344)	(0.0317)		(0.0337)			(0.0336)	(0.0247)	(0.0727)	(0.0245)
Credit rating				0.108***	0.0914**			0.0675**	0.00270		
				(0.0402)	(0.0352)			(0.0322)	(0.0537)		
Term to maturity						0.00356					
						(0.0103)					
Amount issued							0.100***	0.0743**	0.103**	0.0867	0.138***
							(0.0321)	(0.0290)	(0.0459)	(0.0905)	(0.0356)
BICS1: Financials									0.0458	0.0434	0.150
									(0.121)	(0.121)	(0.130)
BICS1: Utilities									0.105	0.0162	0.206**
									(0.153)	(0.114)	(0.0963)
Constant	0.171***	-0.0171	0.0837	-0.141	-0.182*	0.0366	-0.447**	-0.508**	-0.517*	-0.416	-0.921***
	(0.0544)	(0.0530)	(0.0567)	(0.103)	(0.101)	(0.0851)	(0.193)	(0.194)	(0.308)	(0.555)	(0.217)
BICS1: Others	-	-	-	-	-	-	-	-	Yes	Yes	Yes
Currencies: All	-	-	-	-	-	-	-	-	Yes	-	-
Observations	112	112	112	112	112	112	112	112	112	27	21
R^2	0.08	0.14	0.20	0.05	0.18	0.00	0.09	0.22	0.58	0.50	0.79
Adjusted R^2	0.07	0.13	0.18	0.04	0.16	-0.01	0.07	0.20	0.54	0.35	0.72

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

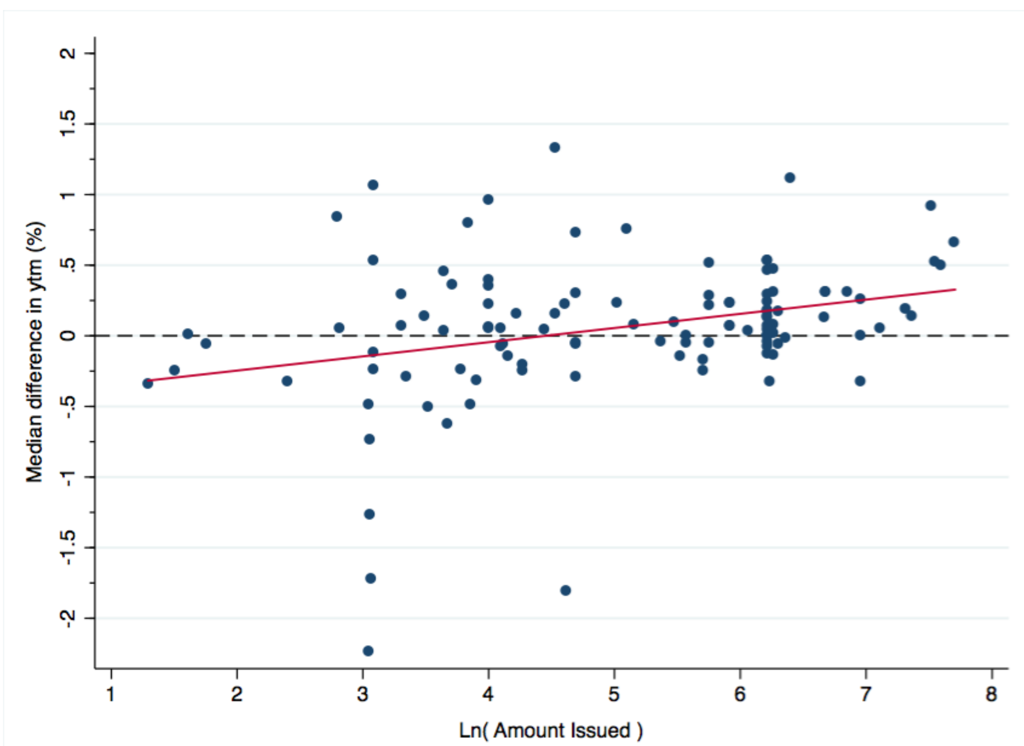
Figure 2 – Relations between the yield differential and its determinants

This figure depicts the results of regressions (2) and (7) from Table 7. Panel (a) shows the relation existing between the median difference in yield to maturity ($Median\ \Delta y_i$) and the median difference in modified duration ($Median\ \Delta md_i$) between the green and conventional bond. Panel (b) depicts the relation between ($Median\ \Delta y_i$) and the natural logarithm of the amount issued.

(a)



(b)



just described. From regression (9) we note that, when the median difference in modified duration between green and conventional bonds increases by 100 bps, the yield differential increases by 8.5 bps, on average. In the case of USD and EUR bonds, its coefficient amounts to 0.192 and 0.0796, respectively. If on one hand it captures the sensitivity of the yield differential to a widening of the spread in modified duration, on the other it allows me to control for residual discrepancies in maturity date and coupon rate between the bonds considered in each pair. In fact, the modified duration of a bond depends positively on its (residual) term to maturity and negatively on its coupon rate. Table E3 (Appendix) shows the results of regressions (2), (8) and (9) for two separate subsets of bonds. The first considers those pairs with a distance in maturity dates of less than 36 months, whereas the second considers those for which such distance is shorter than 6 months. As expected, the coefficient of $Median\ \Delta md_i$ is close in magnitude to that seen in Table 7 but loses part of its significance due to the lower mismatch existing between bonds' maturity dates.

Other two factors affecting the dependent variable are the bond's credit rating and amount issued. They are both significant at the 5% level when considered together with the $Median\ \Delta md_i$, in regression (8). However, after adding controls for market sector (BICS1) and currency of issue in regression (9), only the amount issued remains significant. Given that the latter is proxied using a logarithmic transformation, its coefficient of 0.103 indicates that an increase of 10 percent in the amount issued determines an increase in the yield differential of 1 bp, on average[7]. Ceteris paribus, a green bond with an amount issued of USD 1 billion has a yield differential that is, on average, 10 bps higher than that of a green bond with an amount issued of USD 100 million. The relation just described is depicted in Panel (b) of Figure 2. In the case of EUR bonds, the coefficient of the amount issued equals 0.138, which suggests that such variable has a higher influence on the yield differential. As far as USD bonds are concerned, such effect is lower in magnitude and not significant at the 10% level.

The positive coefficients of both credit rating and amount issued are consistent with the considerations made above when testing the magnitude and significance of the average yield differential. They indicate that green bonds with a higher amount issued or a lower credit rating are likely to have greater values of the yield differential and, therefore, result less expensive than comparable conventional bonds. Furthermore, the last two columns of Table 7 show that the effect of a bond's issued amount on the yield differential is very close, in the case of USD and EUR bonds, to that registered for the entire data sample.

[7] In my set of regressions, I choose to use the natural logarithm of the amount issued because it is characterized by a less skewed distribution that the absolute value. Furthermore, it allows me to make considerations on the effect of the amount issued in relative terms. My choice differs from that of Zerbib (2017), who considers the absolute amount issued (expressed in USD billions). As a robustness check, I perform a separate set of regressions considering the same variable used by the other author which, eventually, confirms the existence of a positive relation between the $Median\ \Delta y_i$ and the amount issued of the green bond. On the other hand, considerations on absolute values (and changes) have to be made in such case.

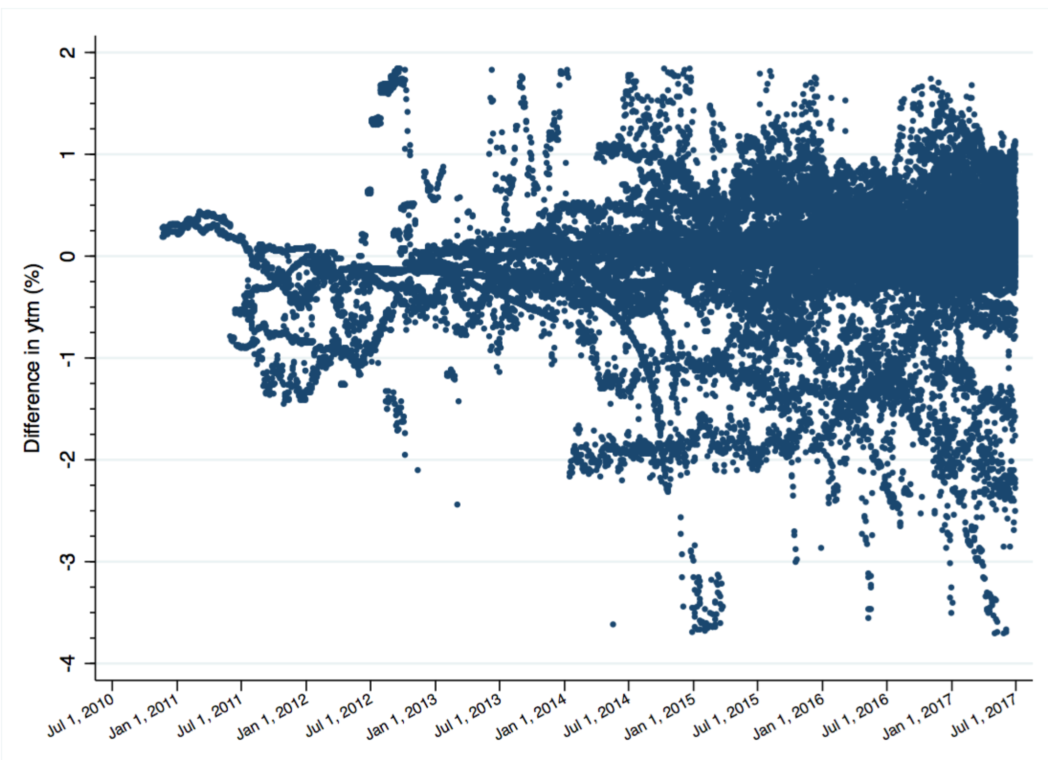
Concerning the $Median\ y_i^{GB}$ and the term to maturity (at issue) of the green bond, regressions (3) and (6) point out that they do not have a distinct and significant effect on the yield differential. As indicated by the value of the adjusted R^2 in regression (6), the explanatory power of bond's tenure (at issue) is almost null.

4.1.3 Time persistence of the daily yield differential

To evaluate the level of persistence over time of the daily yield differential ($\Delta y_{i,t}$), I focus on the relation existing between such variable and its lagged values. Figure 3 contains a graphical representation of the daily yield differential for all green bonds included in the data sample. Each dot represents the $\Delta y_{i,t}$ of a specific pair of bonds on the corresponding date. Taken together, they provide an indication of how such variable evolved over time. As expected, we see that the daily difference in yield to maturity between green and conventional bonds fluctuates around zero. However, from 2014 onwards it concentrates more in the positive domain, confirming the previous results. From the first date in which data is available (November 23, 2010) we note that there has been a widening of its distribution which is explained by the increasing growth and diversification of the green bond market.

Figure 3 – Distribution of the daily yield differential over time

This figure shows the distribution of the difference in yield to maturity between green and conventional bonds (Δy_i) over the period 30 November 2010 – 30 June 2017.



Indeed, the growing issuance of green bonds with different characteristics, such as currency of issue, term to maturity and credit rating, has increased significantly the variety of bonds available in the market and, in turn, the yield they offer. This is confirmed by the I4CE (2016) which argues that, as the green bond market grows, we observe an increasing diversification of both green bonds and issuers. Another factor which contributes to explaining the trend of the daily yield differential relates to changes in bond prices, ultimately reflected in bond yields. Fluctuations may stem from both temporary market imbalances and other one-off events, not documented in my study. Nevertheless, my previous analysis focuses on $Median\ \Delta y_{i,t}$, thus removing the effect of extraordinary events.

The first step consists of a correlogram analysis aimed at understanding which model best fits the time series of data. For all pairs, the autocorrelation function (ACF) tends to zero exponentially whereas the partial autocorrelation function (PACF) becomes systematically null after the fourth lag. Thus, the model that best proxy the trend of the daily yield differential appears to be an autoregressive model with four lags, indicated as AR(4). The latter is specified as:

$$\Delta y_{i,t} = \alpha_i + \beta_1 \Delta y_{i,t-1} + \beta_2 \Delta y_{i,t-2} + \beta_3 \Delta y_{i,t-3} + \beta_4 \Delta y_{i,t-4} + \varepsilon_{i,t}$$

where $\Delta y_{i,t-k}$ is the k-th period lagged difference in yield to maturity. Note that there may be differences among the pairs considered with regard to the number of lags that should be included in the model. For this reason, Table 8 considers four specifications of an autoregressive model with lags ranging from one to four, plus a fifth regression including controls for the following variables: credit rating, amount issued, term to maturity (at issue), market sector (BICS1) and currency of issue. We see that both the one- and two-period-lagged daily yield differential are significant at the 1% level for all specifications[8]. As suggested by the values of the Bayesian (BIC) and Akaike (AIC) Information Criteria, the model that should be preferred for describing the trend of $\Delta y_{i,t}$ is, indeed, an autoregressive model of order two. Contrarian to the fourth lag, the first two remain highly significant also in regression (5), which controls for bond features. The results, shown in Table 8, suggest that the daily yield differential is highly persistent over time. In fact, a coefficient of 0.907 indicates that it converges towards its long-term average at a very slow rate. While for one-lag autoregressive models the coefficient of the one-period-lagged variable has a straightforward interpretation, autoregressive models with a greater number of lags usually have very different dynamics. Rather than interpreting directly the estimated coefficients, they are usually studied by considering the impulse response functions (IRFs) associated with the model. However, that goes beyond the scope of my analysis, which is rather focused on evaluating the time persistence of the daily yield differential.

[8] Being significant at the 1% level is equivalent being significant with a 99% confidence level.

Table 8 – Results of the autoregressive models on the daily yield differential

This table contains the results of the regressions with dependent variable the difference in yield to maturity between green and conventional bonds at time t ($\Delta y_{i,t}$). The independent variables considered in the first four regressions are the one- to four-period lagged Δy_i, which are added sequentially to the set of independent variables.

$$\Delta y_{i,t} = \alpha_i + \beta_1 \Delta y_{i,t-1} + \beta_2 \Delta y_{i,t-2} + \beta_3 \Delta y_{i,t-3} + \beta_4 \Delta y_{i,t-4} + \varepsilon_{i,t}$$

The fifth regression considers also variables on the following bond features: credit rating, amount issued, term to maturity (at issue), market sector and currency of issue. "Credit rating" is a numerical variable ranging from 1 (AAA) to 4 (BBB). "Term to maturity" is the term to maturity (at issue) expressed in years. "Amount Issued" is expressed as the natural logarithm of the amount issued. BICS1 and Currency are qualitative dummy variables whose reference modalities are "Government" and "US Dollar" respectively. The model used in regression (5) can be specified as:

$$\Delta y_{i,t} = \alpha_i + \sum_{j=1}^{4} \beta_j \Delta y_{i,t-j} + \beta_5 Rat_i + \beta_6 Mat_i + \beta_7 Amt_i + \sum_{h=1}^{5} \beta_{7+h}\, BICS1_h + \sum_{k=1}^{12} \beta_{12+k}\, Curr_k + \varepsilon_{i,t}$$

Dep: $\Delta y_{i,t}$	(1)	(2)	(3)	(4)	(5)
$\Delta y_{i,t-1}$	0.907***	0.794***	0.791***	0.789***	0.805***
	(0.0598)	(0.00465)	(0.00467)	(0.00468)	(0.0571)
$\Delta y_{i,t-2}$		0.116***	0.0868***	0.0840***	0.0861***
		(0.00449)	(0.00607)	(0.00608)	(0.0280)
$\Delta y_{i,t-3}$			0.0326***	0.000306	0.00233
			(0.00461)	(0.00616)	(0.0122)
$\Delta y_{i,t-4}$				0.0367***	0.0369*
				(0.00466)	(0.0203)
Credit Rating					0.000693
					(0.00303)
Term to maturity					0.000129
					(0.000381)
Amount Issued					0.0103
					(0.00710)
Constant	-0.00394**	-0.00389***	-0.00393***	-0.00398***	-0.0619
	(0.00170)	(0.000963)	(0.000965)	(0.000966)	(0.0420)
D. BICS1	-	-	-	-	Yes
D. Currency	-	-	-	-	Yes
Observations	48,797	48,685	48,573	48,461	48,461
R^2 (Within)	0.869	0.870	0.870	0.870	-
AIC	-12,305	-12,838	-12,761	-12,695	-
BIC	-12,296	-12,811	-12,726	-12,651	-
Number of bonds	112	112	112	112	112

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

4.1.4 Comparisons with previous studies

Previous studies on the field are those of Barclays (2015) and Zerbib (2017), already presented and discussed in the literature review. Concerning the former, the main differences relate to the set of green bonds, the time horizon and the performance variable considered in the analysis. First of all, such study focuses on the constituents of the Barclays Global Green Bond Index and those of the Global Credit Index[9] and it considers the OAS (Option Adjusted Spread) as dependent variable. Such spread is decomposed into common risk factors and an indicator variable addressing the "greenness" of a bond. Similar to my analysis, Barclays (2015) controls for differences in currencies, credit rating, investment length and bond's age. It finds that green bonds are characterized by an OAS that is 17 bps tighter, after controlling for such variables. The authors of the study argue that the tighter spread may result from a temporary mismatch between demand and supply in the green bond market and may not last indefinitely. As a robustness check, I split my data sample to separately consider green bonds issued before and after August 2015. By doing so, I find that the former set has an average value of the yield differential of -9 bps, supporting the evidence presented by Barclays (2015). On the other hand, such value amounts to 24 bps when considering bonds issued after August 2015. The summary statistics are shown in Table F (Appendix). A potential explanation that could justify such difference relates to the consequences of the COP 21 held in Paris at the end of 2015. As explained before, such conference led the majority of world leaders to actively commit in order to tackle climate change. In the same period, some of the largest institutional investors agreed to work together to foster the expansion and development of the green bond market. As a result, 2016 has been a record year for green bond issuance and, not surprisingly, this may have affected the yield of green bonds.

Regarding the working paper of Zerbib (2017), I build on the considerations made in the literature review. He finds that the average green bond premium is slightly negative for the subsamples of EUR and USD bonds with an amount issued greater than USD 100 million, especially when the credit rating of such bonds decreases. In addition, he finds that the determinants of such premium vary according to the subsample considered. As indicated before, our analyses differ under three dimensions. First of all, the source used to gather data on bonds' performance is different. While he considers ask yields as provided by Bloomberg, I focus on the (annualized) yield to maturity provided by Thomson Reuters Financial Datastream. The second difference stems from the procedure used to match green and conventional bonds. He uses two conventional bonds to create a synthetic bond that perfectly matches the maturity of each green bond and, afterwards, he constructs the daily time series of the bond's yield by linearly interpolating and extrapolating the yields of

[9] The green bond index used in Barclays (2015) does not include "Bloomberg" in its definition because Bloomberg L.P. completed the acquisition of *Barclays Risk Analytics and Index Solution* business in mid-August 2016, whereas the study considers green bonds as of mid-2015. After the acquisition, such index has been named "Bloomberg Barclays Global Green Bond Index".

the two starting bonds, up to the maturity date of the green bond. In my case, after selecting the most similar conventional bond for each green bond considered, I match their daily yields only for the period in which they are both traded. By doing so, I remove the potential biases related to the use of linear extrapolation techniques to predict future yields basing on past data. Furthermore, I account for residual differences in maturity dates between the two bonds by using the median difference in modified duration as an independent variable, when studying the determinants of the yield differential. Lastly, my research differs also with regard to the use of liquidity variables to correct for the residual effect of bond's liquidity. Not having access to information on bond's trading-related variables, such as the daily bid-ask spread, I focus on the absolute value of the daily yield differential. However, considering both the limitations related to the use of the bid-ask spread to control for differences in liquidity and the relatively low magnitude of the adjustment that it implies in the study of Zerbib (2017), such constraint loses part of its relevance.
These three differences are likely to explain the divergence in results between our studies. Furthermore, considering how the distribution of the yield differential changes according to bonds' characteristics, such differences may arise also from a different composition of the two datasets, in terms of issue dates, market sectors and other bond features.

4.1.5 Summary of findings

The results of my analysis at the bond-level indicate that the average value of the yield differential is substantially different across market segments and varies according to bonds' characteristics, such as credit rating and amount issued. In particular, I find that the average yield differential is not statistiscally different from zero in the case of green bonds issued by government-related entities. This result holds also for the subsamples of USD and EUR bonds. With regard to green bonds issued within the sectors "Financials" and "Utilities", the average value of the yield differential amounts to 21 and 38 bps, respectively. However, a more in-depth analysis reveals that these values are driven by USD bonds when the issuer is a financial entity and EUR bonds when the issuer belongs to the utilities sector. Similarly, the average value is found to be positive (21 bps) for the 63 green bonds issued within developed countries. On the other hand, it is not statistically different from zero in the case of bonds issued within developing countries, even if their scarce representation in the dataset does not allow for general conclusions.
In addition, my results suggest that the average yield differential is positively and significantly correlated with the amount issued of the green bonds, whereas the correlation is negative when considering their credit rating. This is confirmed by the results of the cross-sectional regressions used to investigate the determinants of the yield differential. When considering the entire data sample, its main determinants are the median difference in modified duration ($Median\ \Delta md_i$), the amount issued and the credit rating.

As a last step, I document the time persistence of the daily yield differential. The coefficient of the one-lag autoregressive model equals 0.907, thus, suggesting a high level of persistence over time. This is coherent with the fact that the yield differential is due to structural characteristics of the bonds considered.

4.2 Index-level analysis

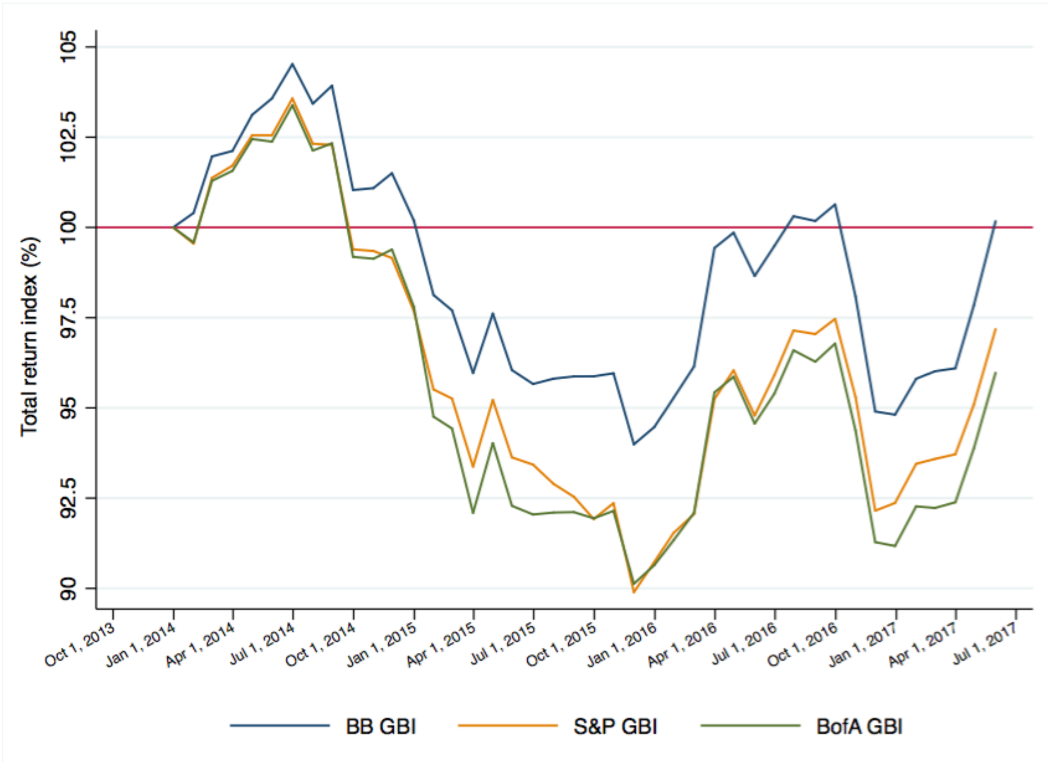
In this section, I document the characteristics and investment styles of three green bond indices (GBI) available in the market: the Bloomberg Barclays Global GBI, the Standard & Poor's GBI and the Bank of America Merrill Lynch GBI[10]. In the remainder of my study I will refer to such indices using the following labels: "BB GBI", "S&P GBI" and "BofA GBI". After that, I use such indices to proxy green bond investments and investigate whether they add value to investors' portfolio, in terms of diversification. Information on the indices are obtained from Bloomberg and the prospectuses provided by index providers. Their main characteristics are summarized in Table G (Appendix). Note that all indices have a multicurrency nature and track the global green bond market. Furthermore, they are all expressed in US Dollars and not hedged against currency movements. As suggested by Kidd (2015), differences in index duration, market value and other bond characteristics result mainly from the criteria used by such indices to determine what constitutes "green". Furthermore, the author points out that a specific feature relates to their role as market benchmark. Indeed, contrarian to common portfolio managers who choose a benchmark according to their desired risk exposure, green bond investors may select the index that best reflect their idea of "greenness".

Despite being all created in 2014, data on total returns are backfilled to different periods, which range from November 2008, in the case of the S&P GBI, to January 2014, in the case of the BB GBI. Figure 4 shows the trend of their monthly total return index, whose time series are obtained from Bloomberg. To compare their performance in relative terms, I have chosen as a starting point the first month for which performance is available for all indices, namely January 2014. As expected, their trend is almost identical. However, we see that the BB GBI has systematically outperformed the other two indices. As mentioned above, the reason that is most likely to explain such outperformance relates to differences in the criteria adopted for bonds' selection. To this extent, the BB GBI has been voted as "the best green bond index available in the market" by the judges of the "Green Bond Awards 2017", thanks to its robust set of criteria as well as the process of research and due diligence that is made to verify the eligibility of every constituent. As argued by Nishikawa (2017), having a set of publicly known criteria helps bringing transparency and consistency in the market. This explains why the BB GBI is used as a benchmark by various financial institutions and tracked by several green bond funds.

[10] "GBI" is used as an abbreviation of the longer "Green Bond Index".

Figure 4 – Total return index of the green bond indices

This figure shows the monthly values of the total return index for the green bond indices considered in my analysis, namely the Bloomberg Barclays Global GBI, the Standard & Poor's GBI and the Bank of America Merrill Lynch GBI. The time horizon considered ranges from January 2014 to May 2017. The former is chosen as a starting point because it is the first date in which performance is available for all three green bond indices.



The considerations made above prove to be relevant for the remainder of my analysis, which is articulated as follows. First, I conduct a return-based style analysis to investigate whether green bond indices reflect any particular investment style. Secondly, I use them as a proxy to evaluate the diversification properties of green bonds for both US and international investors, using mean-variance spanning tests and mean-variance frontier analysis.

4.2.1 Style analysis

I here present the methodology and results of the return-based style analysis performed on the monthly returns of the green bond indices, obtained from Bloomberg. The factors considered are the size, low-risk, value and momentum long-only factor portfolios for the investment grade corporate bond market, as defined by Houweling and Van Zundert (2017)[11]. Another factor that proxies the entire market is added to the

[11] Such data are provided directly by Patrick Houweling (2017), on my request.

regression model. Figure 5 provides a graphical description of the monthly returns for both green bond indices and factor portfolios. Panel (a) confirms what indicated above about the high degree of overlapping between the performance of the three green bond indices. This is not surprising considering that they all track the global green bond market and are not hedged against currency fluctuations. Concerning the monthly returns of factor portfolios showed in Panel (b), it emerges that they have also followed a similar trend since November 2008, reflecting a relatively high degree of homogeneity in corporate bond returns.

The purpose of a standard return-based style analysis, as introduced by Sharpe (1992), is to explain a fund's returns using those of several benchmark portfolios. This analysis requires the factor loadings to be non-negative and sum to one, in order to identify two separate components of return: one related to that of a positively weighted style portfolio and another reflecting the fund-specific return. However, as argued by Ter Horst et al. (2002), these constraints are recommended only in case of relative performance evaluation whereas, in all other cases, they can lead to inconsistent estimates of the factor loadings. As my analysis is not aimed at determining the composition of the benchmark portfolios that mimic green bond indices, I do not impose any constraint on the sign of the factor portfolios' coefficients.

Even if, in practice, portfolio managers and market indices are usually benchmarked using total returns, for the sake of a more robust analysis, I consider also excess returns. For each factor portfolio, Houweling and Van Zundert (2017) calculate the time series of excess returns using a portfolio of duration-matched Treasuries. In my case, due to constraints on data availability with regard to the historical list of constituents of the green bond indices, I calculate their excess returns considering the same portfolio of duration-matched Treasuries used to determine the excess returns of the corporate bond market. As this portfolio may not completely remove the term premium component, it is worth noting that the analysis conducted on excess returns may lead to less accurate estimates of the factor loadings.

The monthly time series of excess returns are showed in Figure C (Appendix). Building on the above considerations, two separate regressions are considered for each green bond index. In the case of total returns, the model can be defined as:

$$TR_{i,t} = \alpha_i + \beta_1 TR_{Market,t} + \beta_2 TR_{Size,t} + \beta_3 TR_{Low-risk,t} + \beta_4 TR_{Value,t} + \beta_5 TR_{Momentum,t} + \varepsilon_{i,t}$$

where $TR_{i,t}$ describes the total return in month t of the green bond index considered. Similarly, for the five factors considered as independent variables, $TR_{x,t}$ represents the total return of factor x in month t. With regard to the analysis made on excess returns, the model specification is the following:

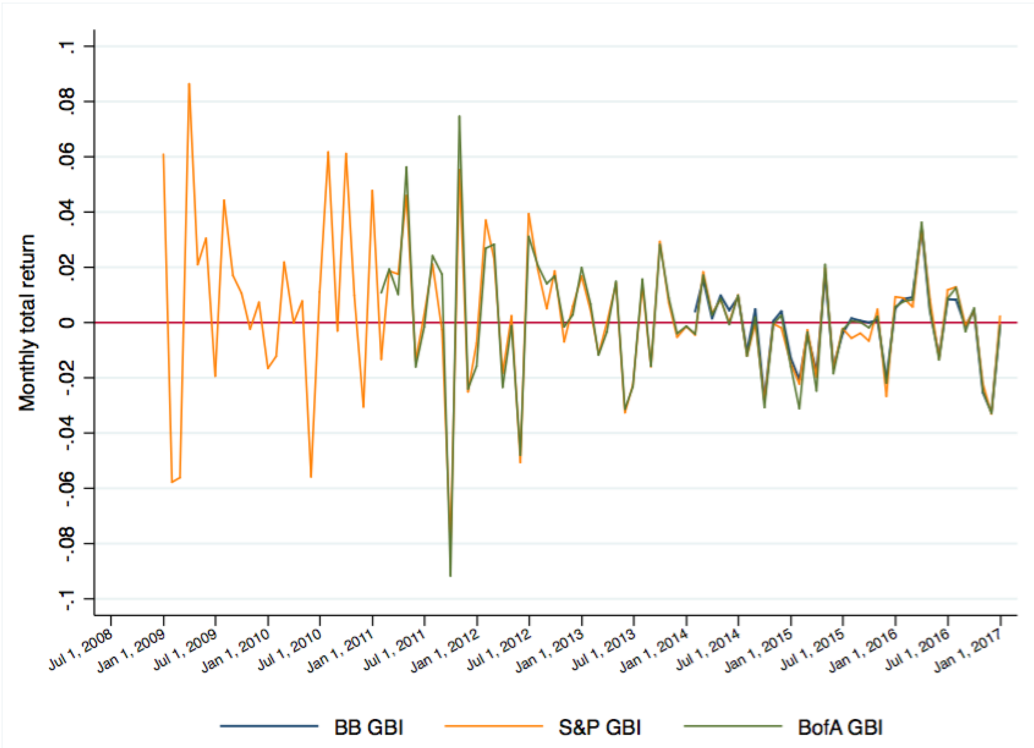
$$ER_{i,t} = \alpha_i + \beta_1 ER_{Market,t} + \beta_2 ER_{Size,t} + \beta_3 ER_{Low-risk,t} + \beta_4 ER_{Value,t} + \beta_5 ER_{Momentum,t} + \varepsilon_{i,t}$$

where $ER_{i,t}$ is the excess return in month t of the green bond index considered and $ER_{x,t}$ represents the excess return of the factor x in month t. The results of the six regressions are presented in Table 9.

Figure 5 – Monthly total returns of the green bond indices and the factor portfolios

This figure describes the time series of the monthly total return for the three green bond indices, the corporate bond factor portfolios and the corporate bond market from November 2008 to December 2016. Panel (a) considers the Bloomberg Barclays Global Green Bond Index (BB GBI), the Standard & Poor's Green Bond Index (S&P GBI) and the Bank of America Merrill Lynch Green Bond Index (BofA GBI). Data Source: Bloomberg (2017). Panel (b) considers the total return of both the corporate bond market and the size, low-risk, value and momentum long-only factor portfolios. The latter are provided directly by Houweling and Van Zundert (2017).

(a)



(b)

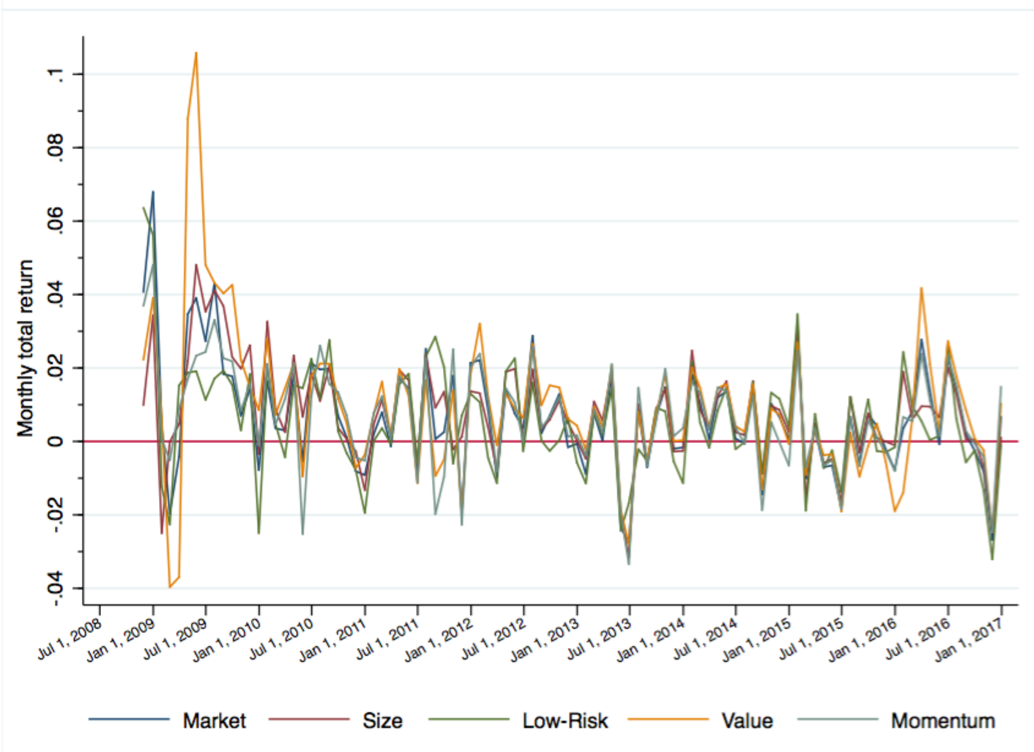


Table 9 – Results of the style analysis on green bond indices

This table shows the results of the style analysis on both total returns and excess returns for three green bond indices, namely: the Bloomberg Barclays Global Green Bond Index (BB GBI), the Standard & Poor's Green Bond Index (S&P GBI) and the Bank of America Merrill Lynch Green Bond Index (BofA GBI). Six regressions are performed. In regressions (1), (3) and (5), the monthly total return of the index considered is regressed against the monthly total returns (TR) of the corporate bond market and the size, low-risk, value and momentum factor portfolios:

$$TR_{i,t} = \alpha_i + \beta_1 TR_{Market,t} + \beta_1 TR_{Size,t} + \beta_1 TR_{Low-risk,t} + \beta_1 TR_{Value,t} + \beta_1 TR_{Momentum,t} + \varepsilon_{i,t}$$

In regressions (2), (4) and (6) the same procedure is presented considering the excess returns (ER) of the factor portfolios over duration-matched Treasuries:

$$ER_{i,t} = \alpha_i + \beta_1 ER_{Market,t} + \beta_1 ER_{Size,t} + \beta_1 ER_{Low-risk,t} + \beta_1 ER_{Value,t} + \beta_1 ER_{Momentum,t} + \varepsilon_{i,t}$$

	BB GBI		**S&P GBI**		**BofA GBI**	
	(1) Total Return	(2) Excess Return	(3) Total Return	(4) Excess Return	(5) Total Return	(6) Excess Return
Market	1.068	1.701	-0.0914	-0.211	1.168	0.835
	(1.215)	(1.370)	(0.681)	(0.693)	(0.997)	(1.035)
Size	-0.866	-0.289	-0.916**	-0.891*	-1.376	-1.255
	(0.847)	(0.845)	(0.432)	(0.463)	(0.833)	(0.863)
Low-risk	-0.0124	-5.355	0.236	0.406	-0.102	-2.011
	(0.679)	(3.358)	(0.428)	(0.831)	(0.661)	(2.950)
Value	-0.464	-0.637	0.0683	0.0483	-0.256	0.022
	(0.605)	(0.635)	(0.257)	(0.331)	(0.551)	(0.566)
Momentum	0.832	0.967	1.606***	1.738***	1.058	1.424*
	(0.687)	(0.715)	(0.478)	(0.478)	(0.718)	(0.737)
Constant	-0.00194	-0.002	-0.00161	-0.00227	0.000322	-0.000679
	(0.00244)	(0.00279)	(0.00262)	(0.00261)	(0.00275)	(0.00318)
Observations	36	36	97	97	72	72
R^2	0.35	0.44	0.34	0.42	0.35	0.46
Adjusted R^2	0.24	0.35	0.31	0.39	0.30	0.42

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

We note that the value of the adjusted R-squared varies from 0.24 to 0.32 in the case of regressions performed on total returns, and from 0.35 to 0.42 when such regressions are performed on excess returns. This suggests that, even after accounting for all factors considered, most of the variability in the returns of green bond indices remains unexplained. When the factor portfolios are considered individually, the coefficients are all positive and, apart from few exceptions, highly significant (Tables H1-H6 in Appendix). Nevertheless, they lose their significance when we consider the complete regressions, whose results are shown in Table 9. This is the case for the BB GBI, which seems not to reflect any particular "factor-related" investment style in its asset allocation. Concerning the S&P GBI, we see that there exists a negative and significant relation with the size factor portfolio, suggesting that such index may favour bonds whose issuers have a relatively large amount of public debt outstanding[12]. Another factor explaining the monthly return of the S&P GBI is the return of the long-only momentum factor portfolio, which indicates the existence of a positive and statistically significant relation between the two. Regarding the BofA GBI, regressions (5) and (6) show that the coefficients of both size and momentum factor portfolios have the same sign and similar magnitude as for the S&P GBI. However, the only coefficient significant at the 10% level is that of the momentum factor portfolio, when the regression is performed on excess returns. In their study, Houweling and Van Zundert (2017) define momentum as the past-six-month return using a one-month implementation lag. Such implementation frequency corresponds exactly to that adopted by the three index providers to rebalance their green bond indices. Hence, it may be case that one of the criteria considered for selecting bonds to be included in the S&P GBI is, indeed, their past-six-month performance. To this extent, Khang and King (2002) find no evidence of momentum in the corporate bond market over the period 1978-1998. In a more recent study considering US corporate bonds from 1991 to 2011, Jostova et al. (2013) suggest that momentum effects are strong in the case of high-yield bonds but completely absent in the subset of investment grade bonds. If we assume that these findings can be extended also to the green bond market, the results contained in Table 9 may partially explain the relative underperformance of S&P GBI and BofA GBI, shown in Figure 4. The results of the style analyses on total and excess returns are presented separately for each green bond index in Tables H1-H6 (Appendix). In the following analysis, I will refer to the above considerations on the characteristics and investment styles of green bond indices.

4.2.2 Mean-variance analysis

In this section, I investigate whether green bonds add value, in terms of diversification, to the portfolios of both US and international investors. What emerged from the previous sections is that green bond indices differ slightly in characteristics and relative performance. However, if we take into account not only their risk-return characteristics but also their correlation with common asset classes, such as stocks and bonds, then the preference ranking resulting from Figure 4 may be subject to changes. Indeed, it is commonly agreed that diversification opportunities are greater when assets correlations are lower. To the best of my knowledge, this is the first academic study that addresses, within its research question, the diversification properties of green bond investments.

[12] According to Houweling and Van Zundert (2017), the size factor long-only portfolio considers the decile of bonds with the smallest size, where the latter is defined by looking at a company's total public debt rather than the amount issued of the bond.

I consider two types of investors who differ with regard to their market focus. I will refer to these two representative agents as "US" and "international" investors, respectively. The asset classes considered in their base-case portfolios are conventional bonds and stocks, which are proxied using the Bloomberg Barclays US Aggregate Bond Index (BB-US BI) and the S&P500 in the case of the US investor, and using the Bloomberg Barclays Global Aggregate Bond Index Unhedged (BB-GL BI) and the MSCI World for what concerns the international investor[13]. The time series of their monthly returns are obtained from Bloomberg. The first columns of Table 10 provide information on the monthly average return and standard deviation of the indices considered, over the period January 2014 - December 2016.

Table 10 – Return, volatility and correlations of the indices

This table shows the pair-wise correlations between the monthly returns of green bond indices, conventional bond indices and equity indices. The green bond indices considered are the Bloomberg Barclays Global Green Bond Index (BB GBI), the Standard & Poor's Green Bond Index (S&P GBI) and the Bank of America Merrill Lynch Green Bond Index (BofA GBI). The conventional bond indices are the Bloomberg Barclays US-Aggregate Bond Index (BB-US BI) and the Bloomberg Barclays Global-Aggregate Bond Index Unhedged (BB-GL BI). All such indices are expressed in US Dollars and unhedged against currency movements. The selected equity indices are the Standard & Poor's 500 (S&P500) and the MSCI World Index (MSCI World). The pairwise correlations are calculated over the sample period for which data is available for both indices considered. Data on the average monthly return and volatility over the period January 2014 – December 2016 are provided in the first columns, under the label "Monthly statistics".

	Monthly statistics		**Correlation Matrix**						
			Green Bond Indices			US Indices		Global Indices	
	Mean (%)	SD (%)	BB GBI	S&P GBI	BofA GBI	BB-US BI	S&P 500	BB-GL BI	MSCI World
BB GBI	-0.14	1.37	1.00						
S&P GBI	-0.21	1.46	0.97	1.00					
BofA GBI	-0.25	1.53	0.98	0.98	1.00				
BB-US BI	0.25	0.87	0.47	0.37	0.34	1.00			
S&P500	0.76	3.10	0.27	0.32	0.33	-0.11	1.00		
BB-GL BI	-0.01	1.46	0.90	0.86	0.85	0.69	0.09	1.00	
MSCI World	0.41	3.20	0.35	0.42	0.40	-0.07	0.96	0.17	1.00

It emerges that the BB GBI has been the best performer among green bond indices since January 2014. In fact, it showed the least negative return (-0.83% annualised) and the lowest volatility (4.74% annualised). With regard to the two conventional bond indices, the monthly statistics of the BB-GL BI appear to be in

[13] The two bond indices considered in the base case portfolio of both US and international investors are expressed in US Dollars and unhedged against currency movements.

line with those of the green bond indices, whereas the BB-US BI is characterized by a higher return and a lower volatility. The difference in volatility is due to the fact that while BB-US BI invests in US bonds only, the other bond indices considered invest globally and are not hedged against currency risk. Nevertheless, the higher return is likely due to a superior performance of the US bond market over the period considered. As expected, we see that there is an almost perfect and positive correlation between the three green bond indices (0.97 - 0.98). This is coherent with the trend of their total return index and with the fact that they all track the global green bond market. Similarly, given their global target, we see that their correlation with the BB-GL BI is twice as large as that existing with the BB-US BI. On the other hand, their pairwise correlations with the equity indices are much lower and range from 0.27 to 0.42.

To determine whether investing in green bonds increases the diversification opportunities of an investor's portfolio, I conduct mean-variance spanning tests for each of the three green bond indices. In doing so, I consider both the case of a US and an international investor, whose base-case portfolios have been defined above. My procedure closely follows that used by Swinkels (2012) to investigate the added value of inflation-linked bonds for domestic and international investment portfolios. This procedure builds on the regression framework developed by Huberman and Kandel (1987). For each green bond index, I define two regressions. The first relates to the case of a US investor and can be specified as follows:

$$R_t^{GBI} = \alpha + \beta_1 R_t^{BB-US\,BI} + \beta_2 R_t^{S\&P500} + \varepsilon_t$$

where R_t^{GBI}, $R_t^{BB-US\,BI}$ and $R_t^{S\&P500}$ are the total monthly returns in period t of the green bond index considered, the BB-US BI and the S&P500. The second regression considers the portfolio of an international investor and has the following specification:

$$R_t^{GBI} = \alpha + \beta_1 R_t^{BB-GL\,BI} + \beta_2 R_t^{MSCI\,World} + \varepsilon_t$$

where R_t^{GBI}, $R_t^{BB-GL\,BI}$ and $R_t^{MSCI\,World}$ are the total monthly returns in period t of the green bond index considered, the BB-GL BI and the MSCI World Index. I use robust standard errors to provide unbiased estimates of the coefficients, which are shown in Table 11.

To test for the mean-variance spanning restriction, which implies both $\alpha = 0$ and $\beta_1 + \beta_2 = 1$, I perform a Wald test. The p-values of such constraints are shown in the last three columns of Table 11. Such test is rejected in all cases at the 10% level, with the only exception being the case in which the BB GBI is added to the portfolio of an international investor. However, the sign of all alphas is negative, suggesting that the diversification opportunities do not imply long positions in green bonds. Given that short positions are almost impossible to obtain in the fixed income market, these results indicate that green bond indices do not add value, in terms of diversification, to the investment portfolios considered.

Table 11 – Results of the mean-variance spanning tests for US and international investors

This table contains the results of the mean-variance spanning regressions for both US and international investors:

$$R_t^{GBI} = \alpha + \beta_1 R_t^{BB\ US\ Agg.} + \beta_2 R_t^{S\&P500} + \varepsilon_t$$

$$R_t^{GBI} = \alpha + \beta_1 R_t^{BB\ Global\ Agg.} + \beta_2 R_t^{MSCI\ World} + \varepsilon_t$$

The former specification relates to the case of a US investor (Panel (a)) and the latter to that of an international investor (Panel (b)). In addition to the estimates of the regression coefficients, the table shows the p-values related to the single and combined tests on the constraints. The first tests whether the intercept α is null, the second whether the β coefficients of the regressions sum to one, and the third one is a joint test of the two previous hypotheses, which is the mean-variance spanning test. *** indicates significance at the 1% level, whereas ** and * indicate significance at the 5% and 10% level, respectively.

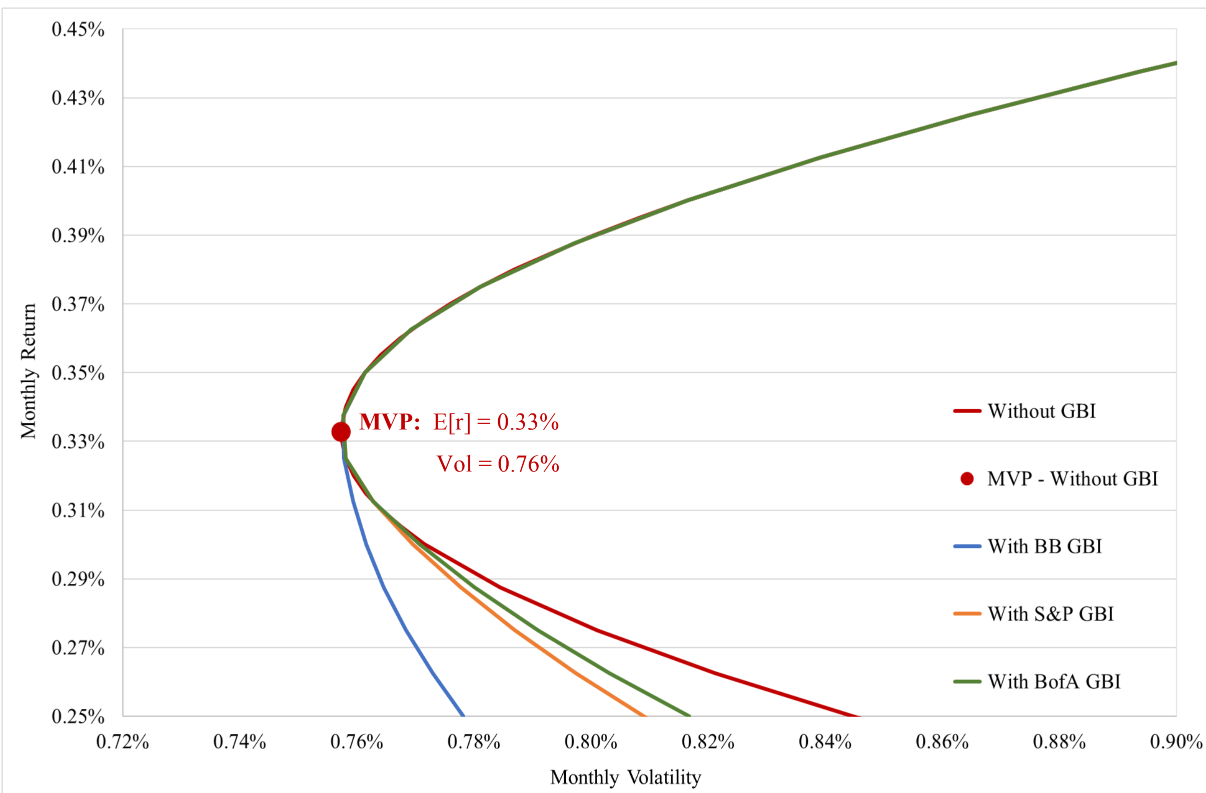
Green Bond Index	**Regression Coefficients**			**Spanning test (p-value)**		
(a) US Investor	Alpha	BB-US BI	S&P500	$\alpha = 0$	$\sum \beta = 1$	Both
BB GBI	-0.005*	0.795**	0.147**	0.05	0.85	0.08
S&P GBI	-0.007***	1.130***	0.458***	0.00	0.00	0.00
BofA GBI	-0.006***	0.968***	0.424***	0.02	0.18	0.06
(b) International Inv.	Alpha	BB-GL BI	MSCI World	$\alpha = 0$	$\sum \beta = 1$	Both
BB GBI	-0.001*	0.815***	0.087**	0.09	0.17	0.17
S&P GBI	-0.003**	0.877***	0.303***	0.02	0.02	0.00
BofA GBI	-0,003*	1,033***	0,294***	0.011	0.00	0.02

The conclusions obtained with the mean-variance spanning tests are corroborated by the results of the mean-variance frontier analysis, which are graphically shown in Figures 6 and 7. In both cases, I do not allow for short sales because of the constraints associated with obtaining such positions in the real bond market. Figure 6 considers the case of a US investor with the additional opportunity of investing in green bonds, proxied using the three indices analysed: the BB GBI (blue line), the S&P GBI (orange line) and the BofA GBI (green line). It can be clearly seen that none of them add value in terms of diversification. In fact, the weights of the minimum variance portfolio remain unchanged, with 91% invested in the US bond market and the remainder in the US equity market. Similarly, Figure 7 shows the case of an international investor with the same additional opportunity of investing in green bonds. It emerges that the diversification benefits of the new asset class are absent when the latter is proxied using either S&P GBI or BofA GBI. This is highlighted by the perfect overlapping existing between the three efficient frontiers. The minimum variance portfolio does not change and remains invested almost completely (97%) in the global bond market, while the remainder is invested in global equities. On the other hand, such portfolio changes significantly when using the BB GBI to proxy green bond investments. The portfolio weight associated to green bonds equals 39%

and the amount invested in global conventional bonds is reduced by the same amount. Nevertheless, while the monthly expected return is reduced from 0.12% to 0.02%, the reduction in monthly volatility is insignificant (-0.01%). Once again, this confirms that investing in green bonds do not provide relevant diversification benefits to US and international investors having a highly diversified portfolio.

Figure 6 – Mean-variance frontier for US investors

This figure contains the mean-variance frontiers in the case of US investors. The red line indicates the frontier for a US investor who has the opportunity to invest in US equities, proxied using the S&P500 Index, and US conventional bonds, proxied using the Bloomberg Barclays US Aggregate Bond Index (BB-US BI). The blue, orange and green lines represent the mean-variance frontiers for a US investor that has the additional opportunity of investing in one of the three following green bond indices: the Bloomberg Barclays Global GBI (blue line), the Standard & Poor's GBI (orange line) and the Bank of America Merrill Lynch GBI (green line). Such indices are expressed in US Dollars and not hedged against currency risk. Short sales are not allowed; thus, all assets have positive weights. The chart shows also the monthly expected return and volatility for the minimum variance portfolio (MVP) without green bond indices.



However, it is worth noting that the monthly returns considered in the previous analysis do not hedge the currency risk, thus they are characterized by higher volatility. As a result, I investigate the added value of green bonds in the case of a US investor who has the additional opportunity of investing in the global green bond market (proxied using the BB GBI) while hedging the embedded currency exposure. The base-case portfolio of such investor is identical to that used in the previous analysis and contains investments in US securities only, which are not affected by foreign currency fluctuations. Data on hedged monthly returns from January 2014 to December 2016 are obtained from Bloomberg. By hedging the currency risk, the volatility of the green bond index is significantly reduced and investors obtain a third potential source of return, next to coupon payments and capital appreciation, namely the hedge return. Over the period considered, the hedged version of the BB GBI is characterized by an average monthly return and volatility of 0.36% and 0.79%, respectively. Such values are much more in line with those of the BB-US BI, indicating that the volatility of unhedged monthly returns is influenced by currency movements.

Figure 7 – Mean-variance frontier for international investors

This figure contains the mean-variance frontiers in the case of international investors. The red solid line indicates the frontier for an international investor who has the opportunity to invest in global equities, proxied by the MSCI World Index, and global conventional bonds, proxied by the Bloomberg Barclays Global Aggregate Bond Index Unhedged (BB-GL BI). The blue, orange and green lines represent the mean-variance frontiers for an international investor that has the additional opportunity of investing in one of the three following green bond indices: the Bloomberg Barclays Global GBI (blue line), the Standard & Poor's GBI (orange line) and the Bank of America Merrill Lynch GBI (green line). Such indices are expressed in US Dollars and not hedged against currency movements. Short sales are not allowed; thus, all assets have positive weights. The chart shows also the monthly expected return and volatility for the minimum variance portfolio (MVP) when green bond indices are not included.

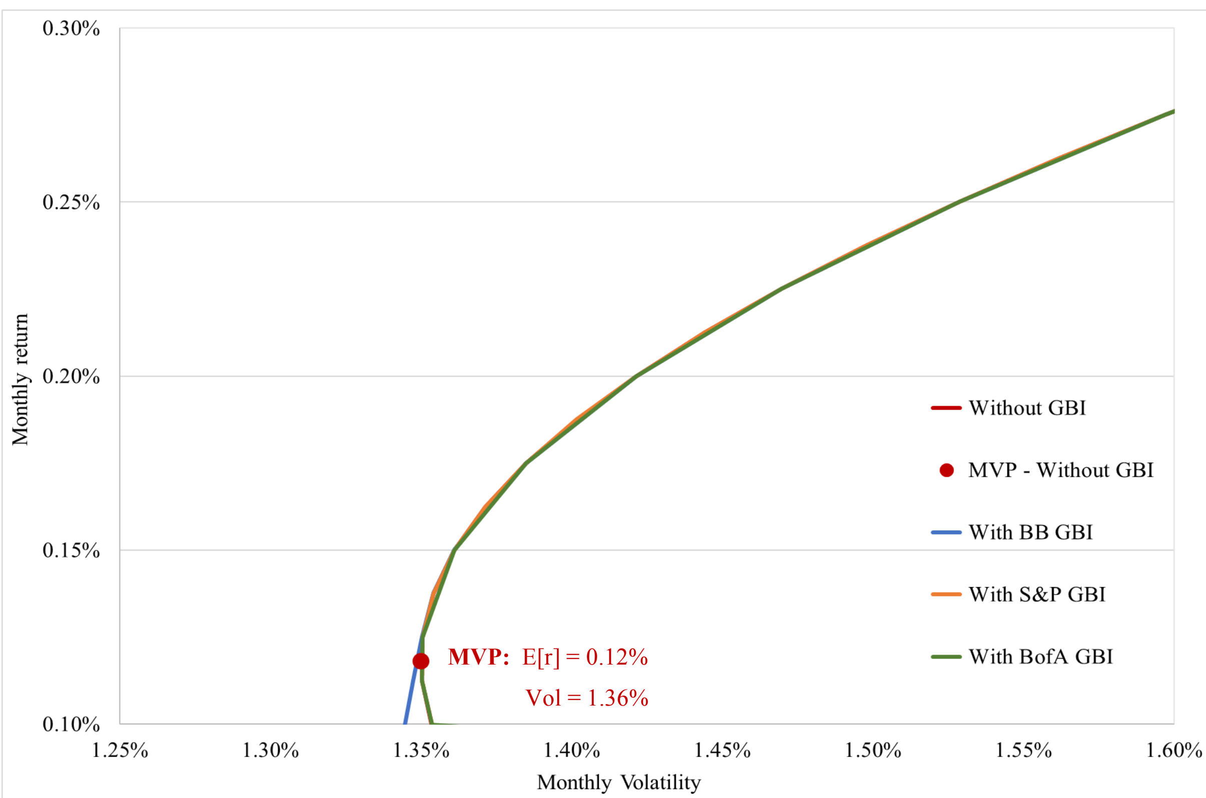


Figure 8 – Mean-variance frontier for US investors that hedge their currency exposure

This figure contains the mean-variance frontiers for a US investor with and without the opportunity of investing in the global green bond market, which is proxied using the Bloomberg Barclays Global Green Bond Index (BB GBI), while hedging its currency exposure. The red line indicates the mean-variance frontier when the investor invests only in US conventional bonds and equities, where the latter are proxied using the Bloomberg Barclays US Aggregate Index (BB-US BI) and the S&P50, respectively. The blue line indicates the mean-variance frontier when the investor includes green bonds within the investment opportunity set. The tables provide information on the portfolio weights and volatility of an investor that requires a monthly return of 0.4% and 0.5%.

Expected monthly return: 0.4%

Portfolio A (blue line)	Portfolio B (red line)
83% Green bonds	0% Green bonds
10% US conventional bonds	82% US conventional bonds
7% US equities	18% US equities
Monthly volatility: 0.75%	**Monthly volatility: 0.82%**

Expected monthly return: 0.5%

Portfolio A’ (blue line)	Portfolio B’ (red line)
79% Green bonds	0% Green bonds
0% US conventional bonds	69% US conventional bonds
21% US equities	31% US equities
Monthly volatility: 0.90%	**Monthly volatility: 1.07%**

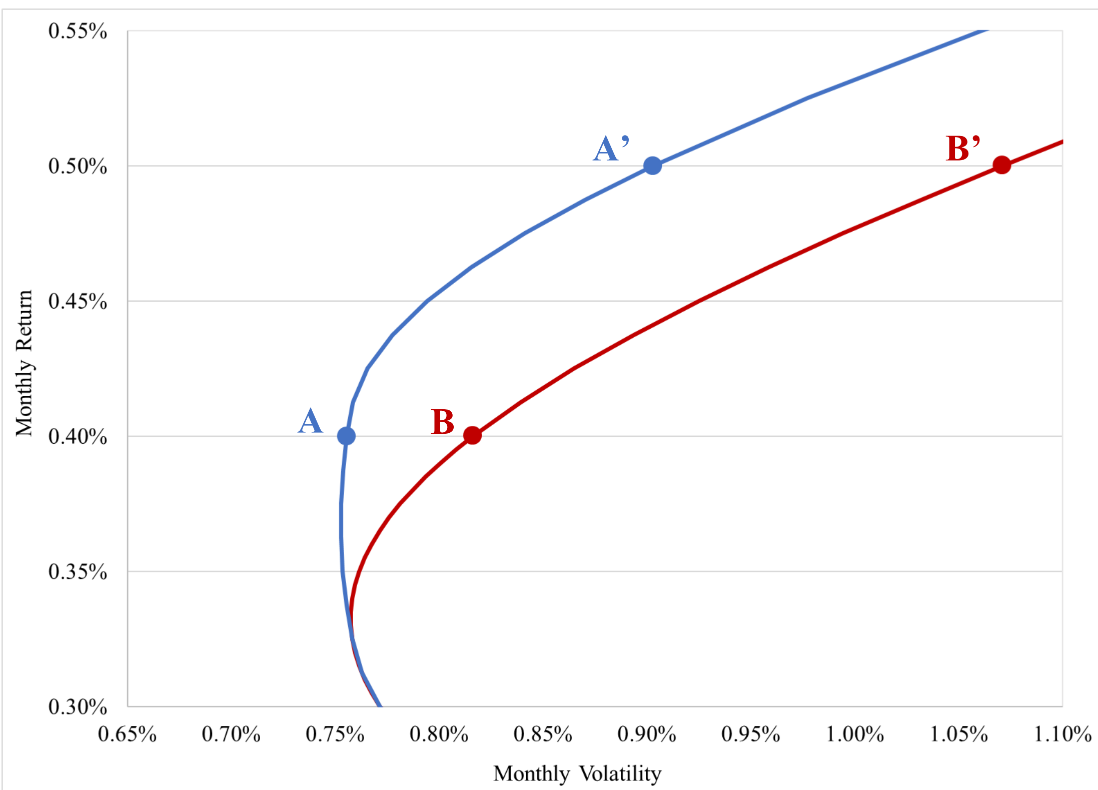


Figure 8 contains the mean-variance frontier for a US investor with and without the opportunity of investing in the global green bond market, while hedging its currency exposure. We see that, the addition of green bonds expands the efficient frontier and highlights the positive effect of hedging currency risk. However, for an investor requiring a monthly return of 0.4% (annualised: 4.9%), the reduction in monthly volatility is negligible and amounts to 0.07% (annualised: 0.25%). On the other hand, the change in portfolio weights is massive. Investments in green bonds account for 83% of the total portfolio, whereas the remainder is almost equally divided between US conventional bonds and equities. Similarly, for an investor requiring a monthly return of 0.5% (annualised: 6.2%), the reduction in monthly volatility is larger and amounts to 0.17% (annualised: 0.59%). The resulting portfolio is invested for 79% in green bonds and 21% in US equities.

The results of the mean-variance frontier analysis are in line with those of the mean-variance spanning tests and suggest that the diversification benefits of investing in green bonds are negligible for both US and global institutional investors, when their base-case portfolios are highly diversified. Similarly, such gains are small in magnitude in the case of US investors that hedge their currency exposure when investing globally. Yet, we cannot generalize these findings to give an exhaustive conclusion about the diversification properties of green bonds. First of all, the bond and stock market indices used to proxy the base-case portfolios of US and international investors may be too broad and diversified to leave room for further diversification. Considering that the magnitude of such improvements is heavily dependent on the initial composition of investors' portfolio, it may still be the case that green bonds provide diversification benefits to less-diversified portfolios, such as those of retail investors. Secondly, the base-case portfolios are proxied considering investments in stocks and bonds only. Despite being the most common and liquid asset classes worldwide, they are not sufficient to address all classes of investors. As a result, green bonds may provide diversification benefits when considering investors that have large exposures to other asset classes, such as real estate and commodities. Last but not least, considering that green bond indices have been created only recently, the length of the time horizon considered in the analysis may not be sufficient to offer an accurate indication of the long-term correlation existing between green bond indices and the other major asset classes, such as stocks and bonds.

4.2.3 Summary of findings

The results of my analysis at the index-level indicate that the three green bond indices considered in my study differ in their characteristics. One of the main differences stems from their definition of "greenness", which determines the criteria that they use to select bonds. If on one hand this diversity increases investors' concerns on how green bond issuers use green bonds' proceeds, on the other it allows portfolio managers and institutional investors to select the benchmark index that most closely reflect their idea of what constitutes "green". With regard to their performance, the BB GBI has outperformed the other two indices since January 2014, both in terms of return and volatility. The merit has been attributed to the robust set of criteria that it employs for the selection of green bonds.

As suggested by the style analysis performed on both total and excess returns, green bond indices do not show a common preference for a specific factor-related investment style. In the case of BB GBI, the factors lose their significance when considered together. On the other hand, S&P GBI reflects a positive and statistically significant correlation with the momentum factor portfolio. This is the case also for BofA GBI, when the style analysis is performed on excess returns. Such correlation suggests that the two index providers may consider the past-six-month performance of green bonds among the criteria used for selecting the index constituents. Furthermore, considering that previous academic literature has found no evidence of momentum effects in the corporate bond market, the relative underperformance of the two green bond indices may be partially due to differences in factor-related investment styles.

The results of both mean-variance spanning tests and mean-variance frontier analysis indicate that the diversification benefits of investing in the global green bond market are insignificant for both US and international investors, when their base-case portfolios are highly diversified. Similarly, in the case of a US investor that hedges his currency exposure when investing globally, I find that the diversification benefits are positive but still negligible. Nevertheless, we cannot generalize such findings for three main reasons. First of all, the bond and stock indices used to proxy investments in US and global markets may be too broad and diversified for green bonds to further increase portfolio diversification. Secondly, I restrict the set of investors considered to those investing in stocks and bonds only, not considering other asset classes. Lastly, given that green bond indices have been introduced recently and the green bond market is still characterized by strong growth and development, we should be aware of the fact that such findings may be subject to change in the future.

5. Conclusions

The growing concerns related to climate change have led to a rapid growth of the green bond market, which now includes a large variety of issuers and currencies. In addition, the increasing regulation is reducing investors' uncertainties, thus bringing greater transparency in the market. Considering such trends and the limited academic literature in the field, my research is aimed at investigating the added value of green bonds for investors' portfolio, both in terms of return and diversification. After matching 112 green bonds with their most similar conventional bond, I evaluate the magnitude and significance of the yield differential, concluding that it is slightly positive (6 bps), on average, and varies according to the market segment considered. An analysis of its determinants suggests that such yield spread depends on specific bond characteristics, such as the amount issued, the credit rating and the spread in modified duration between green and conventional bonds. It is also characterized by a high level of persistence over time, which confirms its structural nature. These findings prove to be useful for investors, as they provide information on the return prospects of different market segments as well as on the bond features that are most likely to influence the yield differential. In the second part of my analysis, I compare three well-known green bond indices available in the market: the Bloomberg Barclays Global GBI, the Standard & Poor's GBI and the Bank of America Merrill Lynch GBI. After evaluating their characteristics, I use them to proxy green bond investments and investigate whether they add value, in terms of diversification, to the portfolios of both US and international investors. I conclude that differences in their definition of "greenness" and selection criteria are likely to influence their investment styles and performance. The results of both mean-variance spanning tests and mean-variance frontier analysis indicate that green bonds do not provide investors with significant diversification opportunities, when their base-case portfolio is highly diversified. Moreover, in the case of a US investor that hedges currency risk when investing in the global green bond market, the diversification benefits are also limited. Nevertheless, such findings cannot be generalized to all classes of investors because of the specific assumptions made on the initial composition of investors' portfolios.

Concerning the limitations of my research, the most important refers to the size of the data sample employed for the bond-level analysis. The latter counts 112 bonds, representing less than 15 percent of the total number of green bonds issued before December 30, 2016. A larger data sample would allow for a more accurate and detailed analysis of the yield differential, thus increasing the reliability of the considerations made for different segments of the green bond market. The same limitation is partially found in the index-level analysis. Due to constraints on data availability with regard to the constituents of the green bond indices, I could not evaluate the effect on index composition of different definitions of "greenness". A second limitation relates to the use of the yield to maturity as a proxy for bonds' performance. Since they are not traded as frequently as other securities, such yield may not reflect their fair value. Other measures, such as the option adjusted spread (OAS), could be considered when performing a similar analysis.

Further research could focus on increasing the size of the dataset used for the analysis at the bond-level, which would also allow for the introduction of further constraints in the bond matching procedure. Moreover, given the increasing number of green bonds issued within developing countries, future studies could analyse the risk-return features of such bonds as well as their role in fostering an environmentally aligned development for such countries. Regarding the analysis made on green bond indices, this study could be extended to focus on the role of green bonds for specific types of institutional investors, such as real estate and sovereign wealth funds. To this extent, I expect the academic literature in the field to develop significantly in the future to keep up with the expansion and development of the green bond market.

All things considered, green bonds do not seem to offer return and diversification prospects that are different from those provided by similar conventional bonds. As a result, it is crucial to understand which factors are driving the growing interest of institutional and retail investors in the green bond market. Among them, an important role is likely played by ESG policies and reputational reasons as well as by the increasing awareness regarding the environmental risks associated with climate change.

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Appendix

Table A – IDR green bonds excluded from the bond-level analysis

This table contains information on the two outlier green bonds excluded from the data sample considered in the bond-level analysis. The conventional bond is the same for both green bonds and is showed on the last column on the right. The median difference in yield to maturity, showed in the last row of the table, is calculated by subtracting the yield to maturity of the conventional bond from that of the green bonds.

Issuer name	European Bank for Reconstruction & Development (EBRD)		
Category	Supranational Authorities		
BICS1	Government		
Currency of issue	Indonesian Rupiah (IDR)		
	1st Green Bond	**2nd Green Bond**	**Conventional Bond**
ISIN Code	XS1208591880	XS1224586872	XS0854915120
Issue Date	4/23/2015	5/28/2015	12/11/2012
Maturity Date	4/24/2019	5/28/2019	12/12/2016
Maturity (years)	4	4	4
Amount (IDR mn)	270,000	230,000	61,000
Amount (USD mn)	20.0	17.1	4.5
Coupon Rate	6.88%	6.91%	4.23%
Coupon Frequency	2	2	12
Coupon Type	Fixed	Fixed	Fixed
Maturity Type	At maturity	At maturity	At maturity
Payment Rank	Sr Unsecured	Sr Unsecured	Sr Unsecured
Rating	AAA	AAA	AAA
Median ytm	9.47	9.41	3.89
Median diff. in ytm	5.64	5.68	-

Table B – Currencies description

This table contains the acronyms and description of the currencies considered in the data sample of 112 green bonds.

ID	**Currency**
AUD	Australian Dollar
BRL	Brazilian Real
CAD	Canadian Dollar
EUR	Euro
GBP	Great British Pound
IDR	Indonesian Rupiah
INR	Indian Rupee
MXN	Mexican Pesos
NOK	Norwegian Krone
SEK	Swedish Krone
TRY	Turkish Lira
USD	US Dollar
ZAR	South African Rand

Table C – Total and average amounts issued

This table shows the distribution of the 112 green and conventional bonds included in the data sample by currency. It contains data on the average and total amount issued (in US Dollars). Information on the average and median amount are provided for the columns showing the mean value of green and conventional bonds issued.

		Green Bond		Conventional Bond	
Currency	**N°**	**Mean**	**Total**	**Mean**	**Total**
AUD	9	102,069,900	918,628,900	224,291,300	2,018,622,000
BRL	4	50,797,190	203,188,800	52,007,560	208,030,200
CAD	4	371,996,100	1,487,984,000	1,041,589,000	4,166,356,000
EUR	21	807,510,100	16,957,710,000	1,271,428,000	26,699,980,000
GBP	2	1,728,182,000	3,456,364,000	2,993,458,000	5,986,915,000
IDR	1	4,527,574	4,527,574	7,414,830	7,414,830
INR	1	21,200,230	21,200,230	73,611,900	73,611,900
MXN	1	101,316,100	101,316,100	62,719,520	62,719,520
NOK	1	173,599,100	173,599,100	173,599,100	173,599,100
SEK	34	86,399,740	2,937,591,000	122,251,600	4,156,554,000
TRY	3	30,745,940	92,237,830	53,545,240	160,635,700
USD	27	526,296,300	14,210,000,000	653,703,700	17,650,000,000
ZAR	4	44,632,130	178,528,500	50,252,730	201,010,900
Average		**311,482,493**		**521,528,652**	
Median		**101,316,100**		**122,251,600**	

Table D – Yield differential for floating-rate and fixed-rate green bonds

This table contains the summary statistics on the median difference in yield to maturity between green and conventional bonds, both in absolute ($Median\ \Delta y_i$) and relative ($Median\ \Delta\% y_i$) terms. Panel (a) considers the former, Panel (b) the latter. Green bonds are divided, according to their coupon type, in “Floating-rate bonds” and “Fixed-rate bonds”. The last line of each panel provides information on the distribution of the corresponding variable for the entire dataset. The statistics considered are: minimum value (Min), 25° percentile (P25), median, mean, 75° percentile (P75), maximum value (Max) and standard deviation (SD).

	Summary Statistics							
	N	**Min**	**P25**	**Median**	**Mean**	**P75**	**Max**	**SD**
(a) Median Δy_i (%)								
Floating-rate bonds	17	-0.29	-0.17	0.04	0.01	0.14	0.36	0.21
Fixed-rate bonds	95	-2.24	-0.06	0.07	0.07	0.31	1.33	0.54
All Bonds	112	-2.24	-0.10	0.07	0.06	0.29	1.33	0.50
(b) Median $\Delta\% y_i$								
Floating-rate bonds	17	-0.57	-0.19	0.13	0.40	0.70	2.28	0.88
Fixed-rate bonds	95	-0.52	-0.04	0.05	0.36	0.30	5.70	0.91
All bonds	112	-0.57	-0.05	0.05	0.37	0.30	5.70	0.90

Table E1 – Results of the cross-sectional regressions for USD bonds

This table shows the results of the cross-sectional regression with dependent variable the median difference in ytm between green and conventional bonds ($Median\ \Delta y_i$). It considers only the 27 USD bonds included in the dataset. Seven regressions are performed. The dependent variable ($Median\ \Delta y_i$), the green bond yield ($Median\ y_i^{GB}$) and the median difference in modified duration ($Median\ \Delta md_i$) are expressed as a percentage (e.g. 2% is indicated as 2). "Credit Rating" is a numerical variable ranging from 1 (AAA) to 4 (BBB). "Term to maturity" is the term to maturity at issue of the green bond (expressed in years). "Amount Issued" is the logarithm of the amount issued (expressed in USD millions). BICS1 is a qualitative dummy variable containing 6 modalities, with reference modality "Government". It controls for the effect of different BICS sectors on the dependent variable.

$$Median\ \Delta y_i = \alpha_i + \beta_1 Median\ y_i^{GB} + \beta_2 Median\ \Delta md_i + \beta_3 Rating_i + \beta_4 Maturity_i + \beta_5 Amount\ Iss_i + \sum_{j=1}^{5} \beta_{5+j}\ BICS1_j + \varepsilon_i$$

Dep: $Median\ \Delta y_i$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Median\ y_i^{GB}$	0.0393						
	(0.0516)						
$Median\ \Delta md_i$		0.210***					0.192**
		(0.0609)					(0.0727)
Credit rating			0.0400				
			(0.0454)				
Term to maturity				-0.0114			
				(0.0166)			
Amount issued					0.150		0.0867
					(0.120)		(0.0905)
BICS1: Financials						0.250*	0.0434
						(0.141)	(0.121)
BICS1: Utilities						0.0215	0.0162
						(0.146)	(0.114)
Constant	0.0531	0.117***	0.0397	0.199	-0.790	0.0585	-0.416
	(0.142)	(0.0411)	(0.107)	(0.138)	(0.744)	(0.0741)	(0.555)
Other BICS	-	-	-	-	-	Yes	Yes
Observations	27	27	27	27	27	27	27
R^2	0.02	0.45	0.04	0.01	0.05	0.18	0.50
Adjusted R^2	-0.03	0.43	-0.003	-0.03	0.01	0.03	0.35

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table E2 – Results of the cross-sectional regressions for EUR bonds

This table shows the results of the cross-sectional regression with dependent variable the median difference in ytm between green and conventional bonds ($Median\ \Delta y_i$). It considers only the 21 EUR bonds included in the dataset. Eight regressions are performed. The dependent variable ($Median\ \Delta y_i$), the green bond yield ($Median\ y_i^{GB}$) and the median difference in modified duration ($Median\ \Delta md_i$) are expressed as a percentage (e.g. 2% is indicated as 2). "Credit Rating" is a numerical variable ranging from 1 (AAA) to 4 (BBB). "Term to maturity" is the term to maturity at issue of the green bond (expressed in years). "Amount Issued" is the logarithm of the amount issued (expressed in USD millions). BICS1 is a qualitative dummy variable containing 6 modalities, with reference modality "Government". It controls for the effect of different BICS sectors on the dependent variable.

$$Median\ \Delta y_i = \alpha_i + \beta_1 Median\ y_i^{GB} + \beta_2 Median\ \Delta md_i + \beta_3 Rating_i + \beta_4 Maturity_i + \beta_5 Amount\ Iss_i + \sum_{j=1}^{5} \beta_{5+j}\ BICS1_j + \varepsilon_i$$

Dep: $Median\ \Delta y_i$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Median\ y_i^{GB}$	0.156*		0.0230					
	(0.0852)		(0.0551)					
$Median\ \Delta md_i$		0.107***	0.104***					0.0796***
		(0.0225)	(0.0208)					(0.0245)
Credit rating				0.0912				
				(0.0708)				
Term to maturity					0.0132			
					(0.0110)			
Amount issued						0.179***		0.138***
						(0.0473)		(0.0356)
BICS1: Financials							0.0100	0.150
							(0.132)	(0.130)
BICS1: Utilities							0.437***	0.206**
							(0.147)	(0.0963)
Constant	0.0601	0.00304	-0.00967	-0.0182	0.0426	-0.965***	0.0567	-0.921***
	(0.0827)	(0.0509)	(0.0618)	(0.171)	(0.128)	(0.280)	(0.0906)	(0.217)
BICS1: Others	-	-	-	-	-	-	Yes	Yes
Observations	21	21	21	21	21	21	21	21
R^2	0.09	0.52	0.53	0.07	0.04	0.31	0.36	0.79
Adjusted R^2	0.05	0.50	0.47	0.02	-0.01	0.28	0.25	0.72

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table E3 – Results of the cross-sectional regressions for bonds with different distances in maturity dates

This table shows the results of the cross-sectional regression with dependent variable the median difference in ytm between green and conventional bonds ($Median\ \Delta y_i$). It considers two separate sets of bonds: a first set of bonds having a distance in maturity dates of less than 36 months and a second one for which such difference is less than 6 months. Three regressions are performed for each of the two sets. The dependent variable ($Median\ \Delta y_i$) and the median difference in modified duration ($Median\ \Delta md_i$) are expressed as a percentage (e.g. 2% is indicated as 2). "Credit Rating" is a numerical variable ranging from 1 (AAA) to 4 (BBB). "Amount Issued" is the logarithm of the amount issued (expressed in USD millions). "BICS1" and "Currency" are qualitative dummy variables containing 6 and 13 values respectively. They are used in regressions (3) and (6) and their reference modalities are "Government", for BICS1, and "US Dollar" for Currency.

Distance in maturity dates:	Less than 36 months			Less than 6 months		
Dep: $Median\ \Delta y_i$	(1)	(2)	(3)	(4)	(5)	(6)
$Median\ \Delta md_i$	0.125**	0.128**	0.0842	0.139	0.130	0.0651
	(0.0578)	(0.0541)	(0.0521)	(0.104)	(0.0834)	(0.105)
Credit rating		0.0656**	0.0254		0.0451	-0.0376
		(0.0325)	(0.0611)		(0.0454)	(0.0346)
Amount issued		0.0752**	0.0943*		0.0466*	0.0231
		(0.0323)	(0.0502)		(0.0265)	(0.0543)
BICS1: Financials			0.0192			0.239
			(0.135)			(0.155)
BICS1: Utilities			-0.0433			
			(0.193)			
Constant	-0.00883	-0.505**	-0.497	0.00680	-0.289**	-0.0830
	(0.0527)	(0.214)	(0.335)	(0.0454)	(0.110)	(0.188)
BICS1: Others	-	-	Yes	-	-	Yes
Currency: All	-	-	Yes	-	-	Yes
Observations	98	98	98	38	38	38
R^2	0.05	0.15	0.49	0.03	0.17	0.35
Adjusted R^2	0.04	0.12	0.37	0.00	0.10	-0.05

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table F – Yield differential for bonds issued before and after August 2015

This table contains the summary statistics on the median difference in yield to maturity between green and conventional bonds, both in absolute ($Median\ \Delta y_i$) and relative ($Median\ \Delta\% y_i$) terms. Panel (a) considers the former, Panel (b) the latter. Green bonds are divided, according to their issue date, in "bonds issued before 31 August 2015" and "bonds issued after 31 August 2015". The statistics considered are: minimum value (Min), 25° percentile (P25), median, mean, 75° percentile (P75), maximum value (Max) and standard deviation (SD).

	Summary Statistics							
	N	**Min**	**P25**	**Median**	**Mean**	**P75**	**Max**	**SD**
(a) Median Δy_i (%)								
Before 31 Aug 2015	62	-2.24	-0.25	-0.03	-0.09	0.13	1.33	0.58
After 31 Aug 2015	50	-0.63	0.05	0.22	0.24	0.31	1.06	0.32
(b) Median $\Delta\% y_i$								
Before 31 Aug 2015	62	-0.52	-0.10	-0.01	0.12	0.12	1.87	0.51
After 31 Aug 2015	50	-0.57	0.05	0.20	0.67	0.70	5.70	1.16

Table G – Characteristics of the green bond indices

This table describes the main characteristics of the three green bond indices considered in my analysis, namely the Bloomberg Barclays Global GBI, the Standard & Poor's GBI and the Bank of America Merrill Lynch GBI. Such characteristics are listed in the first column and are collected from the Bloomberg and the prospectuses provided by the index providers. "GBP" and "CBI" stands for "Green Bond Principles" and "Climate Bond Initiative", respectively.

	Bloomberg Barclays Global GBI	Standard & Poor's GBI	Bank of America Merrill Lynch GBI
Launch date	November 2014	21 July 2014	30 October 2014
First value date	1 January 2014	28 November 2008	31 December 2010
Track	Global green bond market	Global green bond market	Global green bond market
Sector	Corporate, government-related and securitized bonds	Corporate, government, and multilateral issuers	Corporate and quasi-government issuers
GBP / CBI alignment	Independent evaluation by MSCI ESG Research	Bonds flagged as "green" by Thomson Reuters and CBI	Labelled green bonds
Weighting scheme	Market-value weighted	Market-value weighted	Market-value weighted
Rebalancing frequency	End of month	End of month	End of month
Calculation frequency	End of day	End of day	End of day
Countries/currencies	Multi-currency benchmark	Any country/currency	Developed and developing
Currency of conversion	US Dollar	US Dollar	US Dollar
Excluded	Restrictions on bond characteristics apply	Restrictions on bond characteristics apply	Restrictions on bond characteristics apply
Credit quality	Investment grade only	Investment grade only	Investment grade only
Coupon type	Fixed-rate only	Fixed, Zero, Step-up, Fixed-to-Float, Floaters	Fixed-rate or with a temporary fixed-schedule

Table H1 – Results of the style analysis on total returns for BB GBI

This table shows the results of the style analysis on total returns for the Bloomberg Barclays Global Green Bond Index USD Hedged (BB GBI). Ten regressions are performed, with dependent variable the monthly total return (TR) of the index. The independent variables are the monthly total returns (TR) of the corporate bond market and the size, low-risk, value and momentum factor portfolios (source: Houweling and Van Zundert, 2017):

$$TR_{BB\ GBI,t} = \alpha + \beta_1 TR_{Market,t} + \beta_1 TR_{Size,t} + \beta_1 TR_{Low-risk,t} + \beta_1 TR_{Value,t} + \beta_1 TR_{Momentum,t} + \varepsilon_t$$

Dep: $TR_{BB\ GBI,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$TR_{Market,t}$	0.585***		1.050**		0.859***		0.438		-0.102	1.068
	(0.166)		(0.392)		(0.303)		(0.444)		(0.614)	(1.215)
$TR_{Size,t}$		0.468**	-0.545							-0.866
		(0.190)	(0.416)							(0.847)
$TR_{Low-risk,t}$				0.365**	-0.306					-0.0124
				(0.170)	(0.282)					(0.679)
$TR_{Value,t}$						0.484***	0.136			-0.464
						(0.144)	(0.381)			(0.605)
$TR_{Momentum,t}$								0.643***	0.746	0.832
								(0.170)	(0.642)	(0.687)
Constant	-0.00345	-0.00351	-0.00263	-0.00259	-0.00342	-0.00347	-0.00352	-0.00351*	-0.00349	-0.00194
	(0.00207)	(0.00231)	(0.00215)	(0.00225)	(0.00207)	(0.00211)	(0.00211)	(0.00203)	(0.00206)	(0.00244)
Observations	36	36	36	36	36	36	36	36	36	36
R^2	0.27	0.15	0.30	0.12	0.29	0.25	0.27	0.30	0.30	0.35
Adjusted R^2	0.25	0.13	0.26	0.09	0.25	0.23	0.23	0.28	0.25	0.24

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

Table H2 – Results of the style analysis on excess returns for BB GBI

This table shows the results of the style analysis on excess returns for the Bloomberg Barclays Global Green Bond Index USD Hedged (BB GBI). Ten regressions are performed, with dependent variable the monthly excess return (ER) of the index. The independent variables are the monthly excess returns (ER) of the corporate bond market and the size, low-risk, value and momentum factor portfolios (source: Houweling and Van Zundert, 2017):

$$ER_{BB\ GBI,t} = \alpha_i + \beta_1 ER_{Market,t} + \beta_1 ER_{Size,t} + \beta_1 ER_{Low-risk,t} + \beta_1 ER_{Value,t} + \beta_1 ER_{Momentum,t} + \varepsilon_t$$

Dep: $ER_{BB\ GBI\ ,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$ER_{Market,t}$	1.118***		1.087**		1.637***		1.747*		-0.0484	1.701
	(0.276)		(0.466)		(0.392)		(1.032)		(0.734)	(1.370)
$ER_{Size,t}$		1.606***	0.0682							-0.289
		(0.528)	(0.825)							(0.845)
$ER_{Low-risk,t}$				3.948	-5.761*					-5.355
				(2.641)	(3.180)					(3.358)
$ER_{Value,t}$						0.645***	-0.410			-0.637
						(0.180)	(0.647)			(0.635)
$ER_{Momentum,t}$								1.078***	1.118*	0.967
								(0.236)	(0.655)	(0.715)
Constant	-0.005**	-0.007***	-0.005**	-0.006**	-0.002	-0.005**	-0.005**	-0.005**	-0.005**	-0.002
	(0.00217)	(0.00251)	(0.00249)	(0.00287)	(0.00252)	(0.00225)	(0.00220)	(0.00207)	(0.00212)	(0.00279)
Observations	36	36	36	36	36	36	36	36	36	36
R^2	0.33	0.21	0.33	0.06	0.39	0.28	0.33	0.38	0.38	0.44
Adjusted R^2	0.31	0.19	0.28	0.03	0.35	0.25	0.29	0.36	0.34	0.35

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

Table H3 – Results of the style analysis on total returns for SP GBI

This table shows the results of the style analysis on total returns for the Standard & Poor's Green Bond Index (S&P GBI). Ten regressions are performed, with dependent variable the monthly total return (TR) of the index. The independent variables are the monthly total returns (TR) of the corporate bond market and the size, low-risk, value and momentum factor portfolios (source: Houweling and Van Zundert, 2017):

$$TR_{S\&P\ GBI,t} = \alpha + \beta_1 TR_{Market,t} + \beta_1 TR_{Size,t} + \beta_1 TR_{Low-risk,t} + \beta_1 TR_{Value,t} + \beta_1 TR_{Momentum,t} + \varepsilon_t$$

Dep: $TR_{S\&P\ GBI,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$TR_{Market,t}$	0.802***		1.341***		1.422***		1.743***		-0.0914
	(0.163)		(0.295)		(0.305)		(0.429)		(0.681)
$TR_{Size,t}$		0.523***	-0.688**		-0.484		-0.298		-0.916**
		(0.188)	(0.316)		(0.373)		(0.412)		(0.432)
$TR_{Low-risk,t}$				0.449**	-0.327		-0.545		0.236
				(0.187)	(0.319)		(0.379)		(0.428)
$TR_{Value,t}$						0.445***	-0.265		0.0683
						(0.123)	(0.250)		(0.257)
$TR_{Momentum,t}$								1.025***	1.606***
								(0.166)	(0.478)
Constant	-0.002	-0.001	-0.001	0.0005	-0.001	-0.001	-0.001	-0.003	-0.002
	(0.00264)	(0.00299)	(0.00272)	(0.00280)	(0.00276)	(0.00280)	(0.00276)	(0.00253)	(0.00262)
Observations	97	97	97	97	97	97	97	97	97
R^2	0.20	0.08	0.24	0.06	0.25	0.12	0.26	0.29	0.34
Adjusted R^2	0.20	0.07	0.23	0.05	0.23	0.11	0.23	0.28	0.31

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

Table H4 – Results of the style analysis on excess returns for SP GBI

This table shows the results of the style analysis on excess returns for the Standard & Poor's Green Bond Index (S&P GBI). Ten regressions are performed, with dependent variable the monthly excess return (ER) of the index. The independent variables are the monthly excess returns (ER) of the corporate bond market and the size, low-risk, value and momentum factor portfolios (source: Houweling and Van Zundert, 2017):

$$ER_{S\&P\ GBI,t} = \alpha_i + \beta_1 ER_{Market,t} + \beta_1 ER_{Size,t} + \beta_1 ER_{Low-risk,t} + \beta_1 ER_{Value,t} + \beta_1 ER_{Momentum,t} + \varepsilon_t$$

Dep: $ER_{S\&P\ GBI,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$ER_{Market,t}$	1.095***		1.443***		1.616***		1.820***		-0.211	-0.211
	(0.173)		(0.297)		(0.295)		(0.429)		(0.667)	(0.693)
$ER_{Size,t}$		0.946***	-0.539							-0.891*
		(0.241)	(0.374)							(0.463)
$ER_{Low-risk,t}$				1.528***	-1.419**		-1.240*		-0.0849	0.406
				(0.432)	(0.658)		(0.714)		(0.770)	(0.831)
$ER_{Value,t}$						0.552***	-0.181			0.0483
						(0.113)	(0.277)			(0.331)
$ER_{Momentum,t}$								1.193***	1.399***	1.738***
								(0.154)	(0.463)	(0.478)
Constant	-0.00405	-0.00469	-0.00266	-0.00330	-0.00290	-0.00358	-0.00287	-0.00432*	-0.00410	-0.00227
	(0.00253)	(0.00296)	(0.00269)	(0.00290)	(0.00254)	(0.00271)	(0.00255)	(0.00235)	(0.00247)	(0.00261)
Observations	97	97	97	97	97	97	97	97	97	97
R^2	0.30	0.14	0.31	0.12	0.33	0.20	0.33	0.39	0.39	0.42
Adjusted R^2	0.29	0.13	0.30	0.11	0.32	0.19	0.31	0.38	0.37	0.39

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

Table H5 – Results of the style analysis on total returns for BofA GBI

This table shows the results of the style analysis on total returns for the Bank of America Merrill Lynch Green Bond Index (BofA GBI). Ten regressions are performed, with dependent variable the monthly total return (TR) of the index. The independent variables are the monthly total returns (TR) of the corporate bond market and the size, low-risk, value and momentum factor portfolios (source: Houweling and Van Zundert, 2017):

$$TR_{BofA\,GBI,t} = \alpha + \beta_1 TR_{Market,t} + \beta_1 TR_{Size,t} + \beta_1 TR_{Low-risk,t} + \beta_1 TR_{Value,t} + \beta_1 TR_{Momentum,t} + \varepsilon_t$$

Dep: $TR_{BofA\,GBI,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$TR_{Market,t}$	0.767***		2.041***		1.527***		0.0781		-0.589	1.168
	(0.202)		(0.389)		(0.275)		(0.528)		(0.586)	(0.997)
$TR_{Size,t}$		0.376	-1.582***							-1.376
		(0.238)	(0.425)							(0.833)
$TR_{Low-risk,t}$				0.0985	-1.022***					-0.102
				(0.220)	(0.273)					(0.661)
$TR_{Value,t}$						0.756***	0.689			-0.256
						(0.184)	(0.489)			(0.551)
$TR_{Momentum,t}$								0.848***	1.382**	1.058
								(0.187)	(0.563)	(0.718)
Constant	-0.00243	-0.00127	0.000498	0.000291	-0.00192	-0.00333	-0.00329	-0.00282	-0.00264	0.000322
	(0.00263)	(0.00296)	(0.00254)	(0.00285)	(0.00242)	(0.00265)	(0.00268)	(0.00253)	(0.00254)	(0.00275)
Observations	72	72	72	72	72	72	72	72	72	72
R^2	0.17	0.04	0.31	0.00	0.31	0.19	0.19	0.23	0.24	0.35
Adjusted R^2	0.16	0.02	0.29	-0.01	0.29	0.18	0.17	0.22	0.22	0.30

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

Table H6 – Results of the style analysis on excess returns for BofA GBI

This table shows the results of the style analysis on excess returns for the Bank of America Merrill Lynch Green Bond Index (BofA GBI). Ten regressions are performed, with dependent variable the monthly excess return (ER) of the index. The independent variables are the monthly excess returns (ER) of the corporate bond market and the size, low-risk, value and momentum factor portfolios (source: Houweling and Van Zundert, 2017):

$$ER_{BofA\,GBI,t} = \alpha_i + \beta_1 ER_{Market,t} + \beta_1 ER_{Size,t} + \beta_1 ER_{Low-risk,t} + \beta_1 ER_{Value,t} + \beta_1 ER_{Momentum,t} + \varepsilon_t$$

Dep: $ER_{BofA\,GBI,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$ER_{Market,t}$	1.668***		1.937***		1.996***		1.694**		0.663	0.835
	(0.233)		(0.443)		(0.438)		(0.737)		(0.796)	(1.035)
$ER_{Size,t}$		2.171***	-0.517							-1.255
		(0.428)	(0.724)							(0.863)
$ER_{Low-risk,t}$				8.668***	-2.578					-2.011
				(1.758)	(2.914)					(2.950)
$ER_{Value,t}$						1.190***	-0.0202			0.0222
						(0.182)	(0.555)			(0.566)
$ER_{Momentum,t}$								1.339***	0.835	1.424*
								(0.184)	(0.632)	(0.737)
Constant	-0.00421*	-0.0072**	-0.00334	-0.009***	-0.00269	-0.0051**	-0.00419*	-0.00390	-0.00406*	-0.000679
	(0.00241)	(0.00287)	(0.00271)	(0.00302)	(0.00296)	(0.00252)	(0.00248)	(0.00238)	(0.00240)	(0.00318)
Observations	72	72	72	72	72	72	72	72	72	72
R^2	0.42	0.27	0.43	0.26	0.43	0.38	0.42	0.43	0.44	0.46
Adjusted R^2	0.42	0.26	0.41	0.25	0.41	0.37	0.41	0.42	0.42	0.42

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

Table I – List of green bonds included in the dataset

This table contains a list of the 112 green bonds considered in the data sample used for the analysis at the bond-level. For each green bond included in the list it provides information on: ticker, country of the issuer, ISIN ticker, currency of issue (Curr), issue and maturity date, term to maturity at issue (Maturity at issue), amount issued in millions of local currency (Amt (LC mn)), coupon rate (Cpn (%)) and frequency (Cpn Freq.) and credit rating of the bond.

N	Ticker	Issuer Country	Bond ISIN Ticker	Curr	Issue Date	Maturity Date	Maturity at issue	Amt (LC mn)	Cpn (%)	Cpn Freq.	Rating
1	AAPL	United States	US037833BU32	USD	2/23/2016	2/23/2023	7	1500	2.85	2	AA
2	ADSEMI	Cayman Islands	XS1087757263	USD	7/24/2014	7/24/2017	3	300	2.13	2	BBB
3	AFDB	SNAT	AU3CB0240661	AUD	12/15/2016	12/15/2031	15	55	3.50	2	AAA
4	AFDB	SNAT	US00828EAX76	USD	10/18/2013	10/18/2016	3	500	0.75	2	AAA
5	AFDB	SNAT	US00828EBJ73	USD	12/17/2015	12/17/2018	3	500	1.38	2	AAA
6	AFDB	SNAT	XS0511719188	AUD	5/27/2010	11/27/2013	4	88.9	4.68	2	AAA
7	AGFRNC	France	XS1111084718	EUR	9/17/2014	9/17/2024	10	1000	1.38	1	AA
8	ALLRNV	Netherlands	XS1400167133	EUR	4/22/2016	4/22/2026	10	300	0.88	1	AA
9	ASIA	SNAT	US045167CY77	USD	3/19/2015	3/19/2025	10	500	2.13	2	AAA
10	ASIA	SNAT	US045167DR18	USD	8/16/2016	8/14/2026	10	500	1.75	2	AAA
11	ASIA	SNAT	XS0499168846	ZAR	4/15/2010	4/18/2013	3	2093	7.18	2	AAA
12	ASIA	SNAT	XS0782365406	AUD	5/21/2012	5/19/2016	4	15.3	3.14	2	AAA
13	AXSBIN	India	US05463CAD48	USD	6/1/2016	6/1/2021	5	500	2.88	2	BBB
14	AXSBIN	India	XS1410341389	USD	6/1/2016	6/1/2021	5	500	2.88	2	BBB
15	BAC	United States	US06051GEZ81	USD	11/21/2013	11/21/2016	3	500	1.35	2	BBB
16	BAC	United States	US06051GFR56	USD	5/12/2015	5/12/2018	3	600	1.95	2	BBB
17	BPCEGP	France	FR0013067170	EUR	12/14/2015	12/14/2022	7	300	1.13	1	A
18	CASTSS	Sweden	SE0009161607	SEK	10/4/2016	10/4/2021	5	650	1.35	4	BBB
19	CASTSS	Sweden	SE0009161615	SEK	10/4/2016	10/4/2021	5	350	1.88	1	BBB
20	EBRD	SNAT	XS0844521574	IDR	11/8/2012	11/10/2016	4	61000	4.38	12	AAA
21	EBRD	SNAT	XS0953030482	BRL	8/8/2013	5/26/2017	4	155	8.01	12	AAA
22	EBRD	SNAT	XS1039383093	BRL	3/20/2014	9/28/2017	4	93	9.12	12	AAA
23	EBRD	SNAT	XS1081203124	BRL	7/25/2014	7/28/2017	3	110	8.85	12	AAA
24	EBRD	SNAT	XS1237362907	INR	6/30/2015	1/10/2018	3	1440	5.49	12	AAA
25	EDF	France	FR0013213295	EUR	10/13/2016	10/13/2026	10	1750	1.00	1	A
26	EIB	SNAT	US29878TCS15	CAD	11/5/2015	11/5/2020	5	500	1.25	2	AAA
27	EIB	SNAT	US29878TCU60	CAD	9/16/2016	9/16/2021	5	500	1.13	2	AAA
28	EIB	SNAT	XS0465397619	SEK	11/17/2009	2/17/2015	5	2400	2.95	1	AAA
29	EIB	SNAT	XS0465397882	SEK	11/17/2009	2/17/2015	5	550	0.38	4	AAA
30	EIB	SNAT	XS0487618448	BRL	3/15/2010	3/16/2015	5	303.42	8.00	2	AAA
31	EIB	SNAT	XS0852107266	SEK	11/13/2012	11/13/2023	11	2175	2.75	1	AAA
32	EIB	SNAT	XS1051861851	GBP	4/8/2014	3/7/2020	6	1800	2.25	1	AAA
33	EIB	SNAT	XS1107718279	EUR	9/10/2014	11/13/2026	12	1800	1.25	1	AAA
34	EIB	SNAT	XS1198278175	TRY	3/12/2015	3/27/2019	4	175	8.50	1	AAA
35	EIB	SNAT	XS1280834992	EUR	8/27/2015	11/15/2023	8	1900	0.50	1	AAA
36	EIB	SNAT	XS1314336204	CAD	11/5/2015	11/5/2020	5	500	1.25	2	AAA
37	EIB	SNAT	XS1346202184	SEK	1/20/2016	1/20/2021	5	1000	0.63	1	AAA
38	EIB	SNAT	XS1490971634	CAD	9/16/2016	9/16/2021	5	500	1.13	2	AAA
39	EIB	SNAT	XS1500338618	EUR	10/5/2016	11/13/2037	21	1000	0.50	1	AAA
40	EXIMBK	India	XS1209864229	USD	4/1/2015	4/1/2020	5	500	2.75	2	BBB
41	FASFOR	Sweden	SE0006345427	SEK	10/10/2014	10/10/2019	5	400	0.00	4	AA
42	FASFOR	Sweden	SE0007227392	SEK	7/10/2015	7/10/2020	5	200	0.09	4	AA
43	GOTA	Sweden	XS0976165828	SEK	10/3/2013	10/3/2019	6	250	0.00	4	AA
44	HYUCAP	South Korea	US44920UAG31	USD	3/16/2016	3/16/2021	5	500	2.88	2	BBB
45	IBESM	Netherlands	XS1398476793	EUR	4/21/2016	4/21/2026	10	1000	1.13	1	BBB
46	IBRD	SNAT	US45905UGD00	USD	4/24/2009	4/24/2012	3	300	0.79	4	AAA
47	IBRD	SNAT	US45905UKC70	USD	12/15/2011	12/16/2013	2	510	0.50%	2	AAA
48	IBRD	SNAT	US45905UNJ96	USD	8/22/2013	8/24/2015	2	550	0.38%	2	AAA
49	IBRD	SNAT	XS0490347415	MXN	3/5/2010	3/5/2020	10	2100	7.50%	1	AAA
50	IBRD	SNAT	XS0490456034	TRY	3/2/2010	3/2/2017	7	75	10.00%	1	AAA
51	IBRD	SNAT	XS0554299015	AUD	11/16/2010	11/16/2015	5	30	5.40%	2	AAA
52	IBRD	SNAT	XS0647664142	EUR	7/13/2011	7/13/2016	5	20	2.25%	1	AAA
53	IBRD	SNAT	XS0724094932	SEK	12/20/2011	11/12/2014	3	200	3.50%	1	AAA

Table I - Continued

N	Ticker	Issuer Country	Bond ISIN Ticker	Curr	Issue Date	Maturity Date	Maturity at issue	Amt (LC mn)	Cpn (%)	Cpn Freq.	Rating
54	IBRD	SNAT	XS0840338981	AUD	10/23/2012	10/24/2017	5	94.5	2.91%	2	AAA
55	IBRD	SNAT	XS1047440448	EUR	3/20/2014	3/20/2017	3	550	0.25%	1	AAA
56	IBRD	SNAT	XS1198022706	TRY	3/4/2015	3/4/2022	7	75	8.25%	1	AAA
57	IBRD	SNAT	XS1517268105	USD	11/14/2016	12/15/2019	3	100	1.18%	2	AAA
58	INTNED	Netherlands	US44987CAJ71	USD	11/24/2015	11/26/2018	3	800	2.00%	2	A
59	INTNED	Netherlands	US44987DAJ54	USD	11/24/2015	11/26/2018	3	800	2.00%	2	A
60	KBN	Norway	US50048MBX74	USD	2/11/2015	2/11/2025	10	500	2.13%	2	AAA
61	KBN	Norway	US50048MCD02	USD	10/26/2016	10/26/2020	4	500	1.38%	2	AAA
62	KBN	Norway	XS0505713783	ZAR	5/27/2010	5/22/2013	3	230	7.08%	12	AAA
63	KBN	Norway	XS0505714161	AUD	5/27/2010	5/22/2013	3	85	5.23%	2	AAA
64	KBN	Norway	XS0514414605	ZAR	6/28/2010	6/20/2013	3	80	6.60%	12	AAA
65	KBN	Norway	XS0594382631	AUD	3/28/2011	3/30/2015	4	7	5.00%	2	AAA
66	KBN	Norway	XS0595626812	ZAR	3/24/2011	3/24/2015	4	50	7.00%	2	AAA
67	KBN	Norway	XS1188118100	USD	2/11/2015	2/11/2025	10	500	2.13%	2	AAA
68	KBN	Norway	XS1508672828	USD	10/26/2016	10/26/2020	4	500	1.38%	2	AAA
69	KFW	Germany	AU000KFWHAC9	AUD	4/2/2015	7/2/2020	5	600	2.40%	2	AAA
70	KFW	Germany	XS1087815483	EUR	7/22/2014	7/22/2019	5	1500	0.38%	1	AAA
71	KFW	Germany	XS1268337844	GBP	7/30/2015	6/5/2020	5	1000	1.63%	1	AAA
72	KOMINS	Sweden	XS1508534861	SEK	10/25/2016	5/5/2020	4	5000	0.00%	1	AAA
73	LINREI	Cayman Islands	XS1453462076	USD	7/21/2016	7/21/2026	10	500	2.88%	2	A
74	MUFG	Japan	US606822AH76	USD	9/13/2016	9/13/2023	7	500	2.53%	2	A
75	NAB	Australia	AU3CB0226090	AUD	12/16/2014	12/16/2021	7	300	4.00%	2	AA
76	NEDWBK	Netherlands	XS1083955911	EUR	7/3/2014	7/3/2019	5	500	0.63%	1	AAA
77	NIB	SNAT	XS0824127277	SEK	9/7/2012	9/7/2032	20	500	2.75%	1	AAA
78	NIB	SNAT	XS0975173633	SEK	9/27/2013	9/27/2018	5	500	2.41%	1	AAA
79	NIB	SNAT	XS1222727536	SEK	4/23/2015	4/23/2020	5	1000	0.16%	1	AAA
80	NIB	SNAT	XS1347786797	SEK	1/20/2016	1/20/2021	5	1000	0.63%	1	AAA
81	NRWBK	Germany	DE000NWB0AA4	EUR	11/28/2013	11/28/2017	4	250	0.75%	1	AA
82	NRWBK	Germany	DE000NWB0AB2	EUR	11/4/2014	11/5/2018	4	500	0.25%	1	AA
83	OREBRO	Sweden	SE0006371316	SEK	10/16/2014	10/16/2019	5	550	0.00%	4	AA
84	OREBRO	Sweden	SE0006371324	SEK	10/16/2014	10/16/2019	5	200	1.19%	1	AA
85	OREBRO	Sweden	SE0009164213	SEK	10/6/2016	10/6/2021	5	500	0.40%	4	AA
86	OSLO	Norway	NO0010752702	NOK	12/4/2015	9/4/2024	9	1500	2.35%	1	AAA
87	REG	United States	US75884RAT05	USD	5/16/2014	6/15/2024	10	250	3.75%	2	BBB
88	RESFER	France	XS1514051694	EUR	11/9/2016	11/9/2031	15	900	1.00%	1	AA
89	RIKSHM	Sweden	SE0009345622	SEK	11/22/2016	2/22/2022	5	350	0.54%	4	A
90	RIKSHM	Sweden	SE0009345630	SEK	11/22/2016	2/22/2022	5	150	1.25%	1	A
91	SBAB	Sweden	XS1436518606	SEK	6/23/2016	6/23/2021	5	1000	1.05%	1	A
92	SBAB	Sweden	XS1436728916	SEK	6/23/2016	6/23/2021	5	1000	0.32%	4	A
93	SKANE	Sweden	SE0009190481	SEK	10/17/2016	10/18/2021	5	775	0.46%	4	AA
94	SKANE	Sweden	SE0009190499	SEK	10/17/2016	10/18/2021	5	425	0.33%	1	AA
95	SKBKH	Sweden	SE0009357007	SEK	11/30/2016	11/30/2021	5	300	0.52%	4	AA
96	SO	United States	US843646AM23	USD	11/17/2015	12/1/2025	10	500	4.15%	2	BBB
97	SO	United States	US843646AN06	USD	11/17/2015	12/1/2017	2	500	1.85%	2	BBB
98	STANAB	Sweden	SE0007490750	SEK	9/9/2015	9/9/2020	5	500	0.21%	4	AA
99	STANAB	Sweden	SE0009161441	SEK	10/7/2016	10/7/2021	5	375	0.15%	4	AA
100	STANAB	Sweden	SE0009161458	SEK	10/7/2016	10/7/2021	5	200	0.50%	1	AA
101	STOCKL	Sweden	XS1420355023	SEK	5/27/2016	9/27/2021	5	1500	0.75%	1	AA
102	SUFP	France	FR0013015559	EUR	10/13/2015	10/13/2025	10	300	1.84%	1	A
103	TENN	Netherlands	XS1241581096	EUR	6/4/2015	6/4/2027	12	500	1.75%	1	A
104	TENN	Netherlands	XS1432384409	EUR	6/13/2016	6/13/2036	20	500	1.88%	1	A
105	ULFP	France	XS1038708522	EUR	2/26/2014	2/26/2024	10	750	2.50%	1	A
106	ULFP	Sweden	XS1073076991	SEK	6/3/2014	6/3/2019	5	850	2.25%	1	A
107	ULFP	Sweden	XS1073077023	SEK	6/3/2014	6/3/2019	5	650	0.30%	4	A
108	ULFP	France	XS1218319702	EUR	4/15/2015	3/14/2025	10	500	1.00%	1	A
109	UPPS	Sweden	SE0007491014	SEK	9/10/2015	9/10/2020	5	500	0.21%	4	AA
110	VASTER	Sweden	SE0009357320	SEK	11/30/2016	11/30/2021	5	500	0.50%	1	AAA
111	VASTER	Sweden	SE0009357338	SEK	11/30/2016	11/30/2021	5	250	0.52%	4	AAA
112	VDP	France	FR0013054897	EUR	11/18/2015	5/25/2031	16	300	1.75%	1	AA

Figure A – Distribution of the differences in issue and maturity dates

This figure shows the distribution of the difference in issue dates and maturity dates between green and conventional bonds. Such differences are expressed in years and represented on the y-axis.

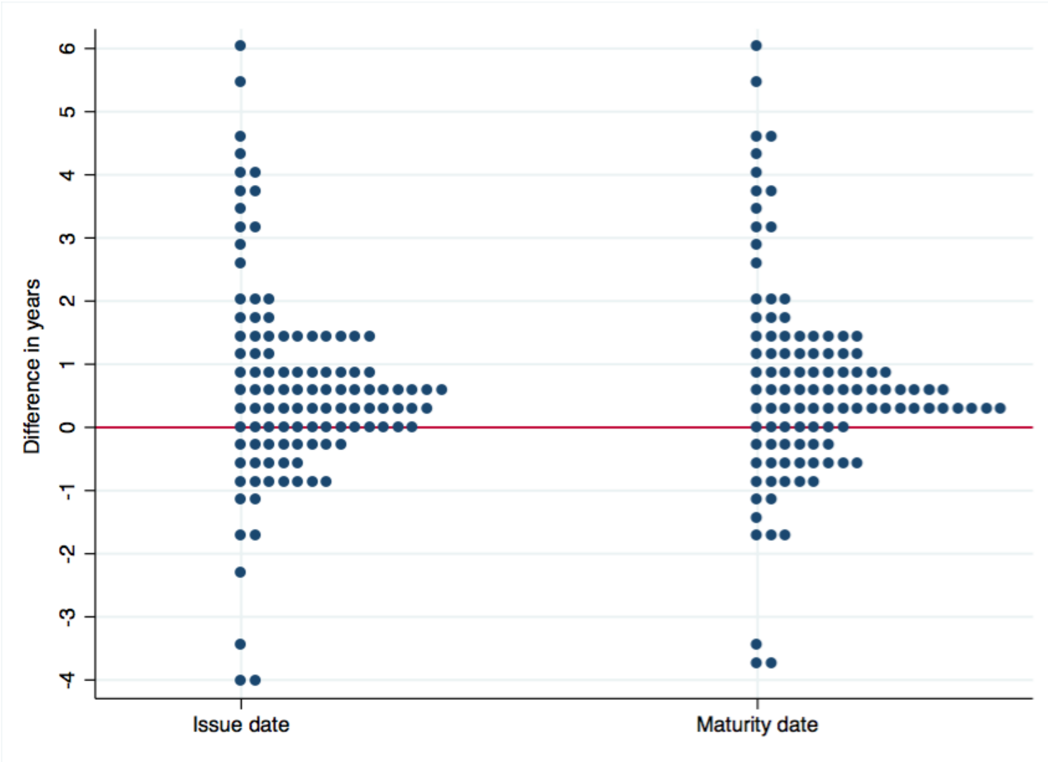
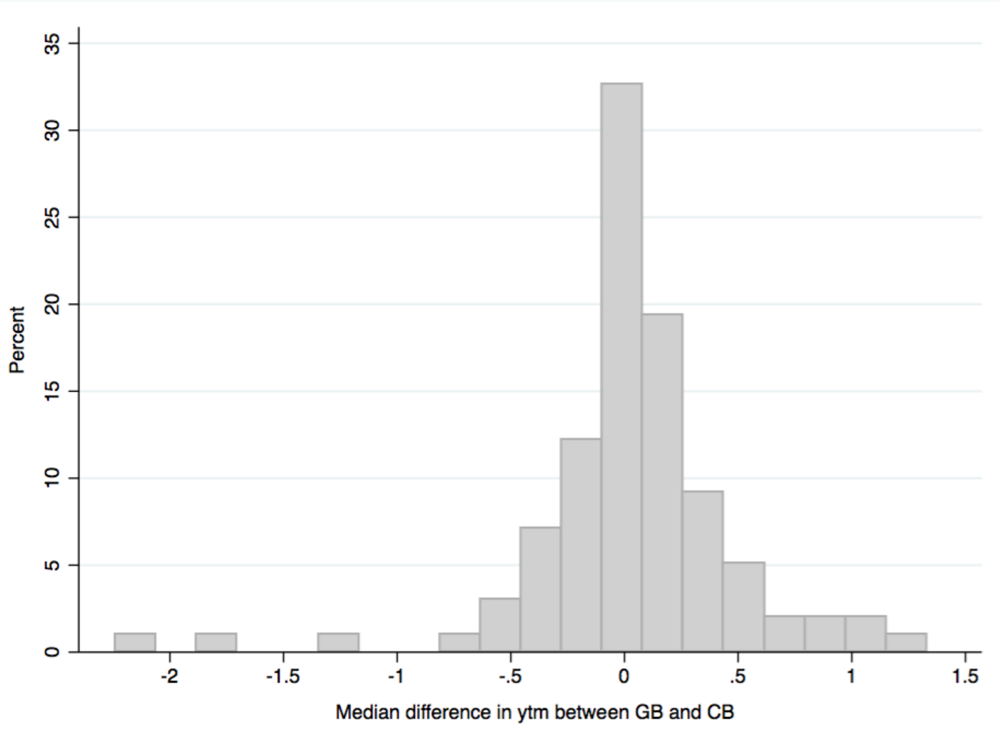


Figure B – Distribution of the yield differential for bonds with different distances in maturity dates

This figure contains the distribution of the median difference in yield to maturity between green and conventional bonds ($Median\ \Delta y_i$) for two different subsamples of the initial dataset. Panel (a) considers 98 bonds with a difference in maturity dates lower or equal to 36 months. Panel (b) considers 38 bonds with a difference in maturity dates lower or equal to 6 months. The two panels contain provide also information on the summary statistics regarding the variable described ($Median\ \Delta y_i$) and the median percentage difference in yield to maturity between green and conventional bonds considered ($Median\ \Delta\% y_i$).

(a)

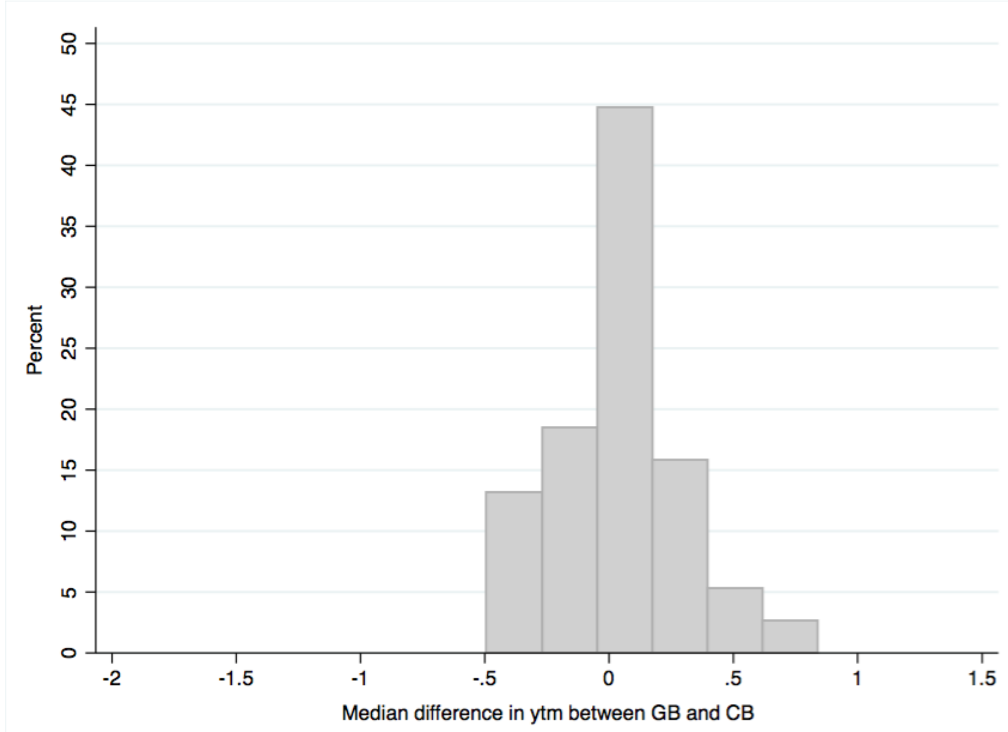
Bonds with a distance in maturity dates lower than 36 months



98 bonds	Summary Statistics Min	P25	Median	Mean	P75	Max	SD
Median Δy_i (%)	-2.24	-0.13	0.05	0.04	0.23	1.33	0.47
Median $\Delta\% y_i$	-0.57	-0.04	0.04	0.30	0.24	5.70	0.89

(b)

Bonds with a distance in maturity dates lower than 6 months

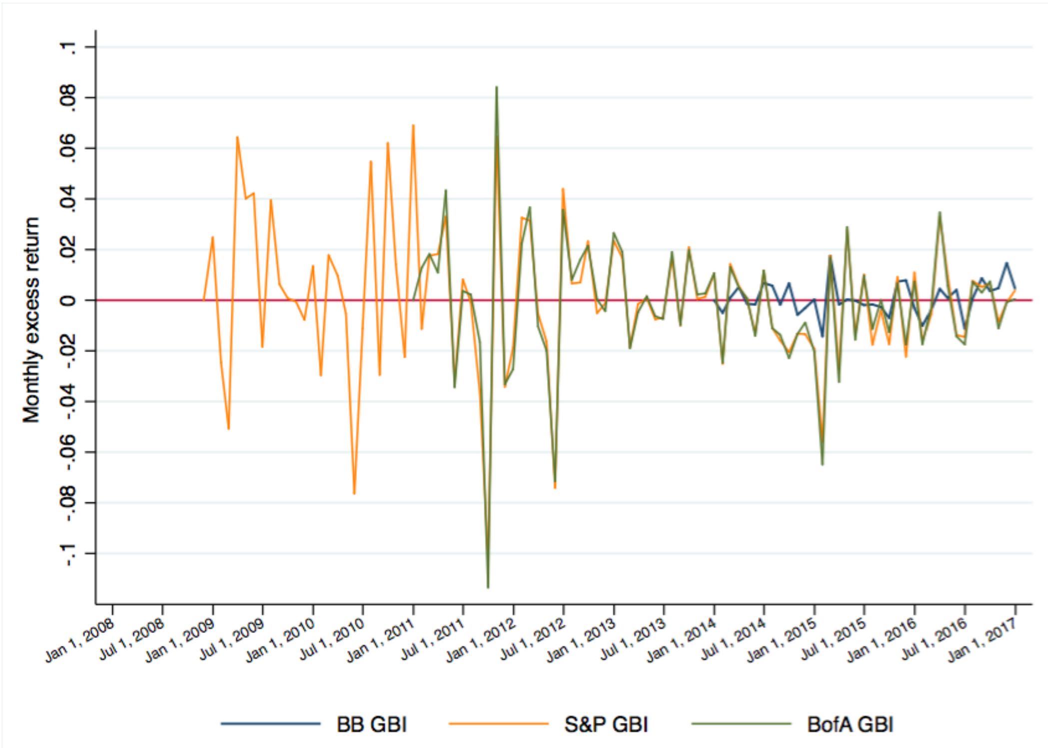


38 bonds	Summary Statistics Min	P25	Median	Mean	P75	Max	SD
Median Δy_i (%)	-0.49	-0.06	0.03	0.03	0.15	0.84	0.26
Median $\Delta\% y_i$	-0.57	-0.04	0.01	0.13	0.15	1.92	0.44

Figure C – Monthly excess returns of the corporate bond market and factor portfolios

This figure describes the time series of the monthly excess return for the three green bond indices, the corporate bond factor portfolios and the corporate bond market from November 2008 to December 2016. Panel (a) considers the Bloomberg Barclays Global Green Bond Index (BB GBI), the Standard & Poor's Green Bond Index (S&P GBI) and the Bank of America Merrill Lynch Green Bond Index (BofA GBI). Data Source: Bloomberg (2017). Panel (b) considers the excess return of both the corporate bond market and the size, low-risk, value and momentum factor portfolios. The latter are provided by Houweling and Van Zundert (2017).

(a)



(b)