ARTICLE IN PRESS

Emerging Markets Review xxx (xxxx) xxx

Contents lists available at ScienceDirect

Emerging Markets Review

journal homepage: www.elsevier.com/locate/emr

Are green bonds priced lower than their conventional peers?

Yue Wu [a,b]

[a] EPFL: Ecole Polytechnique Federale de Lausanne, Switzerland
[b] Swiss Finance Institute (SFI), Switzerland

A R T I C L E I N F O

Keywords:
Green bond market
Green bond premium
Conventional bonds
Bond pricing
Sustainable investment

A B S T R A C T

The green bond market's rapid growth has alerted issuers and investors to this sustainable area of investment. This study ascertains whether green bonds are priced lower than conventional bonds—whether a negative green bond premium exists in both Chinese and global bond markets—and the driving forces behind any such green bond premium. First, an event study is set up to observe stock market's reaction upon issuance of green bonds to test whether green bonds are embedded with additional value by improving the issuer's equity market performance. Then, using the matching method and a two-layer regression process, the study estimates the green bond premium in the Chinese and global markets, respectively, and analyses factors affecting the green bond premium. The event study reveals that green bond issuance could reduce the issuer's equity return performance. The regression models found no significant negative green bond premium in either Chinese or global markets, indicating that green bonds are not priced significantly lower than conventional bonds. However, global market models show that issuing green bonds in CNY could reduce the green bond premium, unlike in USD or EUR.

1. Introduction

Global Warming, a representative form of climate change and primarily attributed to heavy GHG emissions, has caused detrimental impacts on the environment and in turn a huge amount of financial loss, leading people to reflect on transitioning to a sustainable development trajectory. Signed by 196 state parties in 2015, the Paris Agreement[1] initiated by UNFCCC set its long-term temperature goal as keeping the rise in global average temperature to well below 2 °C (3.6 °F) above pre-industrial levels. To do this, the EU legitimised its carbon neutrality goal of 2050 in its European Climate Law, while the President Xi Jinping of China announced China's carbon neutrality goal by 2060 at the UN General Assembly in September 2020, showing a firm determination on transitioning to a net zero carbon emissions economy. Green bonds, as any bond instrument with proceeds that exclusively finance or refinance, partly or fully, new or existing eligible green projects (ICMA, 2018), are often used to finance emission reductions, sustainable developments and other programs intended for reaching the 2 °C target of the Paris Agreement (Agliardi and Agliardi, 2019); while green projects are environmentally-friendly or climate change mitigation projects (Agliardi and Agliardi, 2019; Löffler et al., 2021), such as renewable energy, energy efficiency and other clean and low carbon technologies. Green bonds have features similar to conventional bonds based on issuer characteristics, such as credit risks (Reichelt, 2010); however, compared with conventional bonds, green bonds are mandated to invest proceeds only into projects generating environmental benefits (Kochetygova and Jauhari, 2014).

From supply side, green bond issuers would expect a lower yield (i.e., a lower cost of capital) than conventional bonds because the

E-mail address: yue.wu@epfl.ch.

[1] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

https://doi.org/10.1016/j.ememar.2022.100909
Received 5 March 2020; Received in revised form 12 April 2022; Accepted 15 April 2022
Available online 27 April 2022
1566-0141/

Please cite this article as: Yue Wu, *Emerging Markets Review*, https://doi.org/10.1016/j.ememar.2022.100909

green projects funded has a positive influence for the sustainable and low carbon development, and thus issuers should be rewarded based on the contribution. From demand side, the investors may show a pro-environmental preference (Bakshi and Preclaw, 2015; Zerbib, 2019) thus are willing to pay a higher price and gain a lower return over the green bonds than their conventional peers. Ideally, if both the issuers' expectation and investors' preference are fully reflected in the green bond prices, a negative green bond premium against their conventional peers, later known as "greenium" (Agliardi and Agliardi, 2019; Löffler et al., 2021; MacAskill et al., 2021) and indicating lower risks and lower cost of capital, is to be found. This paper aims to verify the existence of the negative green bond premiums in the real bond markets and answer the following questions: What factors may influence the green bond premium? Do the stocks of issuers perform better in reaction to the green bond issuance announcement, which can be regarded as an implicit benefit to green bond issuers?

The paper begins with an event study in section 3.4 to demonstrate if the stocks of green bond issuers perform better upon the green bond issuance announcement. The paper then adopts a two-layer model structure to justify whether the green bond premium exists in the Chinese and the global market in section 3.3, referenced Bachelet et al. (2019) and Zerbib (2019), and analyze factors leading to the green bond premium. The two-layer model separates liquidity premium (bid-ask spread difference between green bonds and their conventional peers) from green bond premium (ask-yield difference between green and conventional bonds), in order to confirm that the premium is caused by greenness instead of other factors. My modelling intuition to separate the risk into two layers is due to the low percentage of a green bond in general bond issuance. According to Moody's Investors Service, green bonds represented just 2% of total bond issuance over the past two years (Loomis and Sayles, 2020). Hence there is a natural liquidity difference between green bonds and conventional bonds due to the difference in their absolute amounts, and this liquidity difference should be eliminated from the green bond premium. According to Ehlers and Packer (2016) and Bakshi and Preclaw (2015), green bond premiums have a negative correlation with green certification (the factor to describe whether the green bond is verified or externally reviewed as green). In contrast to previous literature, the paper demonstrates that green certification has a positive influence on the green bond premium in both Chinese and global markets, indicating that green certification increases the financing cost of green bonds.

The importance of the paper lies in two aspects: the paper is the first one to provide statistical analysis for both the Chinese RMB denominated green bond market and the global green bond market where green bonds are denominated in various currencies including USD, EUR, and CNY; and the paper is the first to use Chinese bond classification methodology which separates financial and corporate green bonds and to find that, in the Chinese market, green corporate bonds with lower credit rating have larger positive green bond premium than financial ones.

The paper makes several contributions to the literature. Firstly, the paper finds that green certification causes green bond premiums to increase instead of decreasing, while previous literature finds the opposite (Bachelet et al., 2019; Ehlers and Packer, 2016). Secondly, the paper provides a comparative analysis for green bonds denominated in USD, EUR, and CNY and verifies that issuing green bonds in CNY will lower down the green bond premium while issuing green bonds in USD or EUR could increase the green bond premium. To my best knowledge, the paper is the first to conduct a pricing mechanism analysis on the Chinese green bond market by the matching method, and the first one to show that issuing green bonds in CNY could reduce green bond premium and issuers' financing cost. In contrast, comparably, issuing green bonds in USD or EUR may increase the green bond premium and the financing cost. This unique finding suggests that issuing green bonds in emerging market currencies could possibly lower the issuance cost and echoes the finding in Ntsama et al. (2021)that there exists great potential of the green bond markets in low- and middle- income countries (Ntsama et al., 2021).

Additionally, the paper contributes to regulation and policy making for the green bond market: it urges the policy makers to come up with green certification incentives, which should scale up the market from both the supply side and the demand side; issuers are more willing to certify their green bonds, increasing the information transparency and reducing the information asymmetry of the market, while investors as consumers could select green bond to invest in based on the information given by green certification and thus make more sound sustainable investments decisions.

The main conclusion of the papers is as follows: The paper finds a significant positive premium caused by green certification in both Chinese and global markets, showing that getting green bonds certified increases issuers' financing costs. Green certification may suppress the issuance of green bonds in domestic and foreign markets. Main intuitions, methodologies and conclusions are illustrated in the following figure (See Fig. 1).

2. Literature review

As early as 1975, the Nobel Prize winner in Economic Sciences, William D Nordhaus[2] started to include carbon dioxide consideration in economic models (Nordhaus, 1975). After 20 years of exploration, a model that captured all the parts in the DICE model (Dynamic Integrated model of Climate and the Economy) was proposed (Nordhaus, 2019; Nordhaus, 1994; Nordhaus, 1992). In 2005, the announcement of the Stern Review (Stern and Great Britain. Treasury, 2005) by the HM Treasury indicates that climate-policy-incorporated economic theories are considered seriously by policymakers. Since then, financing for a decarbonized economy has gradually become a hot topic and it was found that the demand for investments to fight against climate risks is massive (Ntsama et al., 2021). In 2015, the same year when Paris Agreement was released, the former Governor of the Bank of England, Mark Carney delivered the famous speech "Breaking the tragedy of the horizon – climate change and financial stability" and emphasized that financing the

[2] William D Nordhaus was awarded the Nobel Prize in Economic Sciences in 2018 "for integrating climate change into long-run macroeconomic analysis.". Resource: https://williamnordhaus.com/bio

Fig. 1. Research Structure: main intuitions, methodologies and conclusions.

de-carbonization of the economy calls for more long-term investments and long-term investors (Carney, 2015). The green bond, which usually has a long term to fund green projects, especially green infrastructures, are one of the most suitable sustainable investment tools to fight against climate change meanwhile support the stability of the financial system. The importance of green bonds are again emphasized as a powerful tool to help energy transition towards low carbon economy, and to help scale up renewable energy investing (Sachs et al., 2019), showing a huge potential for the growth of the green bond market.

The green bond market stemmed from an AAA-rated issuance from the European Investment Bank (EIB) and the World Bank in 2007 and has made enormous progress since. By the end of 2020, the cumulative green bond issuance size (since 2012) exceeded USD 1.1 trillion, with 1428 issuers across 71 countries participating in the market(Harrison and Muething, 2021).

2.1. Comparison with conventional bonds

Previous studies propose different definitions of the green bond premium. Nonetheless, the consensus is that the green bond premium should be a yield difference between a green bond and a conventional bond. The matching method is most commonly used as it could directly compare green bonds with their conventional peers.

Zerbib (2019), in justifying whether the yield differential is driven by investors' pro-environmental preferences, implements a matching method by considering matched pairs of green and a conventional bond with identical characteristics, except for their liquidity. Bachelet et al. (2019) implement specific matching criteria to judge which conventional bonds are similar enough to be included in the matched pairs. Hachenberg and Schiereck (2018) also employ the matching method, but require the conventional bonds issue size to reach at least USD 150 million rather than to be similar to the targeted green bonds. The concern to this criterion is that the USD 150 million limitation is not a universal standard for all markets around the world to justify whether the bond is liquid or not. In all three studies, two conventional bonds, with the closest maturity from the same issuer and same characteristics, are selected to build a synthetic, conventional bond (which is used to match the green bonds) by the method of linear interpolation weighted by the conventional bonds' maturities.

Flammer's (2018) 's matching criteria constrain the conventional bond issuers to be "purely conventional" without any green bond issuance instead of being the same issuer as the green bond. This study only chooses one nearest conventional bond neighbour without linear interpolation.

Schmitt (2017) uses the parametric Nelson–Siegel–Svensson approach so that bonds issued in different coupons can be compared with fewer samples excluded. The study inversely removes conventional bonds not aligning to the matching criteria and build a conventional bond yield curve to locate the match for the green bond.

2.2. Green bond premium and pricing mechanism

Different selections of premium proxies have induced different conclusions on premiums. Previous literature Zerbib (2019) uses ask-yield spread has found a negative green bond premium, while Karpf and Mandel (2017), using yield-to-maturity spread, find it favourable. Wulandari et al. (2018) highlights that a liquidity premium might exist on the green bond yield for its disproportional thinness (shortage of supply and excess of demand), and used the LOT (the limited dependent variable model proposed by Desmond, Ogden, and Trzcinka in 1999) liquidity model to solve the unreliable bid-ask spread due to thin trading, and concluded that in recent years the liquidity risk of green bond has lightened. Hachenberg and Schiereck (2018) modify yield measurement by using I-spread, which could separate the interest and credit aspects of the yield. Their study regards the yield's credit aspect as a green bond premium and demonstrates that there is no significant spread difference between green bonds and their conventional peers. The option-adjusted spread (OAS) is later identified as a better proxy for the credit spread for corporate bonds (Nanayakkara and Colombage, 2019). The study supports the existence of negative green bond premiums by concluding that green bonds trade in 62.7 BPS tighter in OAS than the conventional bond.

2.3. Green bond market and stock market

To describe the dependence structure between green bond returns and the financial market, a copula function was built (Reboredo, 2018), as it has the advantage of describing tail dependence during extreme market movements. Combining the copula function with the ARMA process (for conditional means) and TGARCH (for conditional volatilities), the study concludes that the global green bond market weakly comoves with the stock market, indicating that green bonds have sizeable diversification benefits for investors in stock markets. Tang and Zhang (2019) test for stock price reactions to the green bond issuance announcement. By creating an event window and testing whether the cumulative abnormal return (CAR) is significant, they show that the stock market reacts positively to green bond issuance but only to the first-time green bond issues.

2.4. Hypotheses

This study proposes the following hypotheses:

Hypothesis 1. Stock prices of the green bond issuers are positively affected by the announcement of green bond issuance.

The intuition is that the increase of stock prices could be a benefit for green bond issuance and thus as an implicit green premium.

Hypothesis 2. Green bond premiums exist in Chinese green bond markets.

Green bond premium in the Chinese markets can be triggered by green certification, bond type, industry, bond rating, the amount issued, and maturity.

Hypothesis 3. Green bond premiums exist in the global green bond market.

Apart from the factors affecting the Chinese domestic markets, I consider the currency factor for the international market. Green bonds issued in USD, EUR, and CNY may have significant premiums compared with the respective conventional bonds.

3. Data and methodology

3.1. Data

3.1.1. Chinese bond market

I construct the Chinese green bond dataset by augmenting Xinhua Green Bond Database with financial data from Wind and Thomson Reuters. For further details on the data source, please refer to Appendix A-**1**. The full population includes 426 green bonds issued from January 2016 to June 2019, and the sample used in this study includes 146 green bonds with some exclusions due to lack of bond ID, different bond structure and characteristics (Hachenberg and Schiereck, 2018; Tang and Zhang, 2019). For further details on data exclusion, please see Appendix B-**1**.

3.1.2. Global green bond market

This study combines data from Bloomberg, Thomson Reuters, and CBI. 1506 green bonds, issued from March 2010 to June 2019, are included in the initial population. For further details on the data source, please refer to Appendix A-**2**. The final sample used includes 385 bonds issued from February 2016 to June 2018, consisting of green corporate and green government bonds, which can be divided into ten more specific types according to the Bloomberg Industry Classification System (BICS). For further details on data exclusion, please see Appendix B-**2**. ORBIS is used to find green bond issuers' stock ID for the event study.

3.2. Event study

Before the primary regression model, by using a simple event study, I show some preliminary results of possible favourable green bond premiums. This section analyses whether there is any cumulative abnormal return (CAR) around the announcement date of the green bond issuance [CAR calculation method shown in Appendix C-**2**]. The green bond announcement date is defined by Tang and Zhang (2019) as the event date, and the initial event window is counted as ten days before and after the announcement, indicated as [−10,10]. I also tested various event windows such as [−5, 5] and [−5, 10]. My methodology is different from Tang and Zhang (2019) in the way I regress two versions of beta by using a 250-trading-day period data (i.e. [−280, −30]) and 120-trading-day period data (i.e. [−150, −30]). I defined six categories of CAR using SEO[−10,10], SEO[−5,10], and SEO[−5,5], which are the seasoned-offering green bond issuers' equity CAR in 21-, 16-, and 11-day windows, respectively, as well as the first-time-issued green bond issuers' equity CAR in the same windows, defined as FI[−10,10], FI[−5,10], and FI[−5,5], respectively.

The study employed the *t*-test for SEO categories and Wilcoxon signed-rank test for FI categories, as all the FI categories show non-normality [shreds of evidence are shown in Appendix C-**3**]. If there is a significant and positive CAR tested for the stocks of the green bond issuers during any event windows, there may exist an implicit green bond premium from which green bonds issuers could benefit. My results show that seasoned-offering green bond issuance does not influence issuers' stock market performance, while the first-time issuance imposes a negative effect on the green bond issuers' stock performance [results shown in Table 2 in Appendix C-**4**]. To further confirm the negative effects, I also tried the 120-trading-day regressed beta and got the same result. For details of data collection and exclusion for the event study, please refer to Appendix C-**1**.

At this stage, there is no significant negative green bond premium shown by the event study. Therefore, a more robust quantitative model is employed in the following section.

3.3. Regression models

This empirical study ascertains whether a bond premium exists between a green bond and a conventional bond and analyses factors of the green bond premium.

The only difference between the green and conventional bonds should be whether they are classified as "green"; other bond characteristics should be controlled to be the same, which is realized by the matching method (Bachelet et al., 2019; Hachenberg and Schiereck, 2018; Tang and Zhang, 2019; Wulandari et al., 2018; Zerbib, 2019). The matched conventional bond should, at least, have the same issuer, currency, rating, bond structure, seniority, and coupon type. I follow Zerbib's (2019) method to allow for a two-year lead or lag of the conventional bond's maturity date compared with the green bond instead of Bachelet et al.'s (2019) limitation on the coupon rate, which will result in too many exclusions in the database of this study. The maturity rule is a proper proxy for the coupon rate rule because the length of maturity could largely explain the coupon rate difference, as longer maturity leads to higher coupon rate to compensate for larger credit risks. Instead of setting a lower limit on the issue size (Hachenberg and Schiereck, 2018), I require the issue size of the conventional bonds to be 0.25–4 times of green bond's issue size as Bachelet et al. (2019) and Zerbib (2019). I follow Hachenberg and Schiereck (2018) to build a synthetic bond using two existing conventional bonds by Issac Newton's formula as follows:

$$i_{sc} = i_s + \frac{i_l - i_s}{t_l - t_s}\left(t_g - t_s\right) \tag{1}$$

Here, i_{sc}, i_l, and i_s are the spreads of the synthetic, longer-term, and shorter-term conventional bonds, respectively; t_g is the number of months to the green bond's maturity; and t_l and t_s are, respectively, the number of months to the maturity of the longer- and shorter-term conventional bonds.

The study aims at separating green bond premium and liquidity premium from the total green-conventional bond premium. Instead of using i-spread (Hachenberg and Schiereck, 2018) or OAS (Nanayakkara and Colombage, 2019) as the total bond premium, I propose to adopt the more conventional ask-yield spread originally proposed by Bachelet et al. (2019) and Tang and Zhang (2019), given that i-spread and OAS data are not as universally available as ask-yield spreads. In addition, all bonds included are plain vanilla bonds with no need to be adjusted for options, thus OAS does not have added value compared to the easily collected ask-yield spread. The ask-yield spread is defined as:

$$\Delta y_{i,t} = y_{i,t}^{GB} - y_{i,t}^{SCB} \tag{2}$$

where $\Delta y_{i,\,t}$ is the ask–yield difference, while $y_{i,\,t}^{GB}$ and $y_{i,\,t}^{SCB}$ are the ask yield of the green and synthetic conventional bonds, respectively.

This study refers to Zerbib's (2019) method to build two two-layer model structures. In the first layer, the study employed a fixed-effect model to observe how the liquidity spread and green bond premium affect the green-conventional yield spread. In the second layer, only including green bond data, a linear regression model analyses factors that account for the green bond premium.

The first layer of the fixed model is shown below:

$$\Delta y_{i,t} = GP_i + \beta_1 \Delta LiqSpread_{i,t} + BondID\ FE + \varepsilon_{i,t} \tag{3}$$

where $\Delta y_{i,\,t}$ is the ask–yield difference, GP_i (the intercept of the model) is the green bond premium, and $\Delta LiqSpread_{i,\,t}$ is the liquidity spread difference between the green and conventional bonds. The liquidity spread proxy is the bid–ask spread, and $\varepsilon_{i,\,t}$ is the error term.

The second-layer model regarding the Chinese bond market is shown below:

$$\begin{aligned} GP_i = {} & \alpha_0 + \beta_1 GreenCert1_i + \beta_2 AAA_i + \beta_3 AAplus_i + \beta_4 AA_i + \beta_5 AAminus_i + \beta_6 Financials1_i + \beta_7 Corporates_i + \beta_8 CorporatesbyGov_i \\ & + \beta_9 LgIssueAmount_i + \beta_{10} Maturity_i + \beta_{11} ZTDperc_i + \varepsilon_{i,t} \end{aligned} \tag{4}$$

where α_0 is the intercept and $\varepsilon_{i,\,t}$ is the error term. The intuition for including these variables is to include primary factors that could influence the green premium, among which the green certification variable is the unique green bond character, while others (bond credit rating, bond type, issue size, maturity and percentage of zero-trading days) are common factors to possibly affect the green premium in the way that they could influence the yield of both conventional and green bonds.

For the second layer, several interaction variables such as *rating* × *bond type*, *GreenCert* × *rating*, and *GreenCert* × *bond type* are tested to prove whether a specific type of green bond can generate a significant green bond premium.

The second-layer model for the global bond market is shown below:

$$\begin{aligned} GP_i = {} & \alpha_0 + \beta_1 GreenCert2_i + \beta_2 AAA_i + \beta_3 AAplus_i + \beta_4 AA_i + \beta_5 AAminus_i + \beta_6 Aplus_i + \beta_7 A_i + \beta_8 Aminus_i + \beta_9 BBBplus_i + \beta_{10} BBB_i \\ & + + \beta_{11} Financials2_i + \beta_{12} Government_i + \beta_{13} Industrials_i + \beta_{14} Utilities_i + \beta_{15} Energy_i + \beta_{16} RealEstate_i + \beta_{17} ConsumerDiscretionary_i \\ & + \beta_{18} USD_i + \beta_{19} EUR_i + \beta_{20} CNY_i + \beta_{21} SEK_i + \beta_{22} Maturity_i + \beta_{23} ZTDperc_i + \beta_{24} LgIssueAmtUSD_i + \varepsilon_{i,t} \end{aligned} \tag{5}$$

where α_0 is the intercept and $\varepsilon_{i,\,t}$ is the error term. The intuition for including the variables is very similar to that for the Chinese market, except that I also include the currency factors for the international model to emphasize the currency factor affect over the green bond premium.

An overview of all variables in Eq. (5) is listed in Table 1 in Appendix D.

4. Results

4.1. Descriptive statistics

4.1.1. Chinese green bond market

Fig. 4 depicts China's green bond issuance over time. On February 1, 2016, SPD Bank and Industrial Bank issued China's first two green bonds with amounts of CNY 20 and 10 billion, respectively. Since then, green bond issuance in China has experienced a volatile expansion in both the number of bonds and the amount issued. Commercial and policy banks strongly supported the more significant amount issued, and, arguably, the result of the histogram is primarily attributed to the number and amount issued by banks. The most significant monthly amount was issued in November 2018 when the Industrial Bank issued two green bonds with a total of 60 billion. However, the number of bonds issued by corporates, SOEs, and SCEs accounts for over 50% of the total number of bonds issued, indicating their active issuance in smaller amounts.

Table 3 Panel A **in** Appendix D is the full population of the green bonds issued across 2016–2019 in China, including all four types (please see details in Appendix D): Financial Bonds (118 issues), Corporate Bonds (92 issues), Corporate Bonds by Central Enterprises, SOEs & SCEs (106 issues), as well as Green debt Financial Instruments (46 issues). Table 3 Panel B in Appendix D shows the final sample selected by matching criteria mentioned in section 3.3, which shows similarity in composition compared to Panel A. Similar bond characteristics in terms of the issue size, coupon and maturity (See Table 4 in Appendix D for details) could be found between full population and final sample.

Tables 5 and 6**in** Appendix D shows the full and selected panels of the global green bond markets in 2010–2019, in which similar profiles to the Chinese green bond markets in Tables 3 and 4 can be found. However, government bonds accounted for a more significant share in the final global sample due to the large amount issued and longer maturities. Results in Table 3-6 **in** Appendix D show matching criteria do not distort the distributions and essential characteristics of the Chinese and global green bond markets from their original population.

4.1.2. Global green bond market

Fig. 5 illustrates the global green bond issuance since 2010. The green bond market's development is not evident until 2013, and the number and amount issued experienced fast growth after 2016, which is attributed mainly to China. A spike in the amount issued in January 2017 is attributed to the French government, which issued a French Republic Government Bond with a total amount of over USD 20.4 billion.

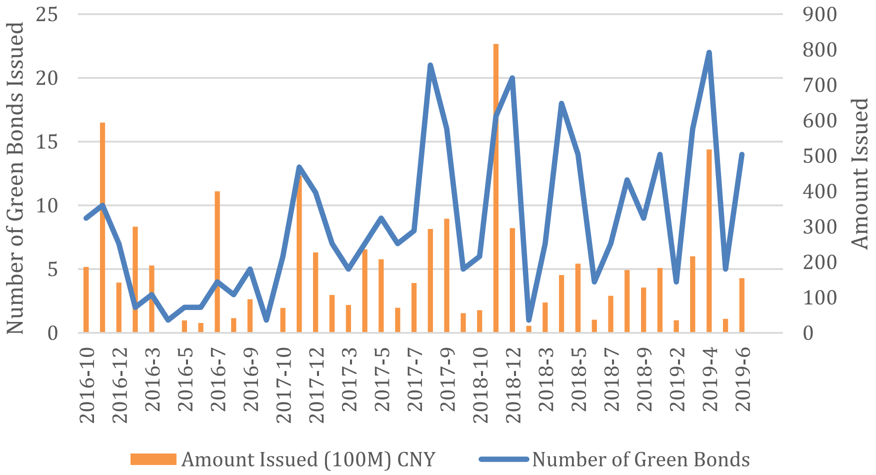

Fig. 4. Number and amount of bonds issued in the Chinese green bond market. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

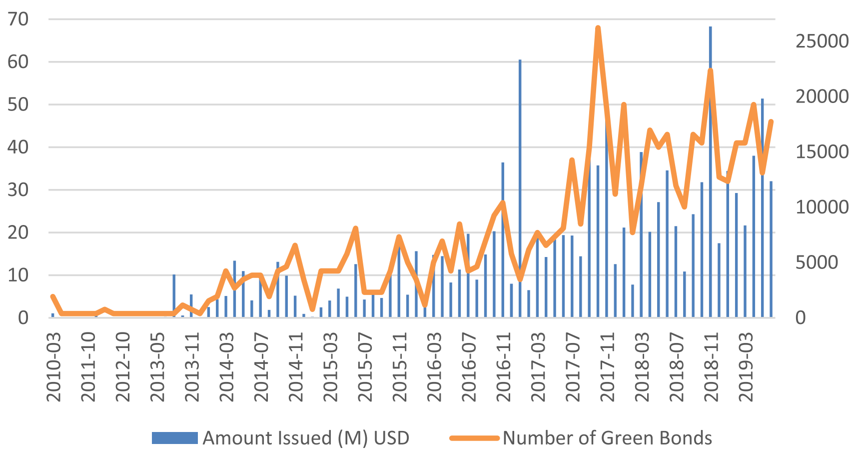

Fig. 5. Number and amount issued in global green bond market. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 7
Descriptive statistics of the first-layer model variables (Chinese green bond market).

Variable	Obs	Mean	Std. Dev.	Min	Max
Y	22,835	0.043	0.339	−1.511	1.865
ΔLiqSpread	22,835	−0.011	0.05	−0.467	0.388

4.2. *Regression results*

4.2.1. *Chinese market*

The first step is to separate the green bond premium from the liquidity spread and further estimate the green bond premium. Table 7 exhibits descriptive statistics of the dependent and independent variables of the first-layer model. The mean of the ask–yield difference is 0.043%, indicating that green bonds averagely have a higher ask yield compared with their conventional peers. Meanwhile, Δ*LiqSpread* has a mean of −0.011%, indicating that green bonds averagely trade tighter (i.e. have a smaller bid-ask spread) than conventional bonds and, thus, have better liquidity. The two variables' descriptive statistics conflict; green bonds have a higher

Table 8
Regression results of first-layer models (Chinese green bond market).

	Dependent variable $\Delta y_{i,\ t}$			
	(1)	(2)	(3)	(4)
	Within Regression	Adjust for autocorrelation	Adjust for heteroskedasticity	Adjust for autocorrelation and heteroskedasticity
ΔLiqSpread	**0.474*****	0.581***	0.711***	0.535***
	(0.040)	(0.011)	(0.012)	(0.006)
_cons	0.048***	0.039***	0.016***	−0.010***
	(0.001)	(0.007)	(0.001)	(0.003)
Obs.	22,835	22,835	22,835	22,835
R^2	0.006			

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

Table 9
Descriptive statistics of the green bond premium (Chinese green bond market).

Variable	Mean	Std. Dev.	Min	25% percentile	50% percentile	75% percentile	Max
GP	**0.034**	0.240	−0.833	−0.099	**−0.002**	0.069	0.774

Table 10
Descriptive statistics of potential effective factors for the green bond premium (Chinese green bond market).

Variable	Mean	Std. Dev.	Min	Max
GreenCert1	0.8	0.4	0	1
AAA	0.559	0.497	0	1
AAplus	0.09	0.286	0	1
Aaminus	0	0	0	0
AA	0.008	0.092	0	1
Financials1	0.438	0.496	0	1
Corporates	0.266	0.442	0	1
CorporatesbyGov	0.084	0.277	0	1
LgIssueAmount	9.308	0.481	8.699	10.301
Maturity	4.365	1.465	3	10
ZTDperc	0.035	0.118	0	0.926

financing cost (higher ask yield) but are more comfortable to trade (lower bid-ask spread).

In model (1) of Table 8, the independent variable proves significant, suggesting that the liquidity spread difference significantly influences the ask–yield spread, and thus the two-layer model structure do make sense because the liquidity spread is sure to exist and could be eliminated to avoid interfering the green premium estimation. The intercept cannot fully represent the green bond premium, as only the intercept estimated with green bond data are green bond premiums. As Table 8 shows, a 1-bp increase in the liquidity spread difference leads to a 0.47-bp (marked in bold font in Table 9) increase in the ask–yield spread between green and conventional bonds. The Wooldridge and modified Wald tests prove the existence of autocorrelation and heteroskedasticity in this case; thus, the feasible generalized least squares (known as "GLS") method is used to address the issues. After adjustment, the liquidity spread difference is still strictly significant at an even higher level.

After the green and conventional bonds' matching process, only 41 green bonds remain in the model database. Including conventional bonds, 113 bonds make up 41 green and conventional bonds triplets (8 conventional bonds are used twice as comparison bonds). Table 10 shows descriptive statistics and the distribution of the green bond premium. Although the 50% percentile is nearly 0, the mean of the green bond premium is slightly larger than 0, indicating that, averagely, the green bonds are 3.4 bps higher in yield than conventional bonds.

The next step is to test which factors lead to a green bond premium. Table 10 shows descriptive statistics of the potential practical factors for the green bond premium. There are no green bonds rated AA- in this dataset; thus, the AA- variable is dropped in the second-layer model for the Chinese market. As suggested by the factors' mean, green bonds rated AAA are in the majority, while relatively fewer bonds are rated AA. Table 11 in Appendix E exhibits the independent variables' correlation matrix. Wherein there is a surprisingly negative correlation between the green certification variable and bonds issued by central enterprises, SOEs, and SCEs. The correlation between financials and corporates bonds is higher compared with others. Moreover, between the percentage of the ZTD variable and corporates bond issued by enterprises, SOEs, and SCEs, there exists a relatively high correlation.

Table 13
Regression results of second-layer models (Chinese green bond market).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
GreenCert1	0.087***	0.088***	0.108***	0.082***	0.070***	0.119***	0.105***	0.086***
	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)
AAA	**−0.033*****	−0.034***	−0.065***	−0.001	−0.035***	−0.009	**−0.078*****	
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	
AAplus	0.230***	0.231***	0.286***	0.229***	0.204***	0.239***		0.250***
	(0.010)	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)		(0.010)
AA	−0.002							
	(0.026)							
Financials1	0.085***	0.085***	0.018***	−0.003			0.055***	0.093***
	(0.008)	(0.008)	(0.007)	(0.007)			(0.008)	(0.008)
Corporates	0.133***	0.132***	0.109***		0.085***		0.144***	0.121***
	(0.008)	(0.007)	(0.007)		(0.006)		(0.008)	(0.007)
CorporatesbyGov	0.175***	0.174***	0.250***			0.136***	0.141***	0.165***
	(0.013)	(0.013)	(0.012)			(0.013)	(0.014)	(0.013)
LgIssueAmount	−0.089***	−0.089***		−0.073***	−0.047***	−0.077***	−0.084***	−0.105***
	(0.007)	(0.007)		(0.007)	(0.006)	(0.005)	(0.007)	(0.006)
Maturity	−0.001						−0.002	
	(0.002)						(0.002)	
ZTDperc	0.378***	0.375***		0.465***	0.542***	0.294***	0.656***	0.367***
	(0.030)	(0.029)		(0.024)	(0.025)	(0.030)	(0.028)	(0.029)
_cons	0.693***	0.692***	−0.099***	0.611***	0.375***	0.618***	0.687***	0.823***
	(0.062)	(0.062)	(0.008)	(0.063)	(0.054)	(0.051)	(0.064)	(0.057)
Obs.	7773	7773	7773	7773	7773	7773	7773	7773
R-squared	0.281	0.281	0.247	0.241	0.259	0.251	0.233	0.278

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

Table 17
Descriptive statistics of the first-layer model variables (global green bond market).

Variable	Obs.	Mean	Std. Dev.	Min	Max
Y	90,543	0.12	0.622	−28.601	3.823
ΔLiqSpread	90,543	**−0.006**	0.101	−7.382	5.354

Both the Breusch-Pagan and White tests confirm that the model has heteroskedasticity, while the variance inflation factors (VIFs) in Table 12 of Appendix E show no obvious multicollinearity. Thus, the White robust standard error estimation is used in the following models.

Chinese green market main model results: As indicated in Table 13, all models reached a similar conclusion: a green bond's green certification could lead to at least 7.0 bps, and 11.9 bps at a maximum yield increase, which means that green certification increases the cost of financing for green bond issuers, in contrast with statements by verifiers such as CBI.[3] LgIssueAmount shows a negative relationship with green bond premium, indicating that green bonds with a more substantial amount issued have a lower financing cost. Compared with the coefficients of other variables, the coefficient of ZTDperc (percentage of ZTDs in the period) is more extensive. The significantly sizeable numerical value of ZTDperc indicates that the illiquidity of green bonds can significantly increase the financing cost for green bond issuers to a considerable degree. Among the three bond rating levels, only AAA can significantly reduce the green bond premium by **3.3** bps at minimum and **7.8** bps at maximum (both marked in bold font in Table 14). Regarding the types of green bonds, although all the coefficients are positive, which means the green bond premium will increase for all types of green bonds, financial bond issuance might lead to a smaller increase in the green bond premium.

Further test: the paper also tries to analyze the Chinese green bond market involves building cross effects between variables to identify and observe more specific types of green bonds regarding their effect on the green bond premium. Table 14 in Appendix E presents descriptive statistics on the cross effects of *rating* × *type*, *certification* × *rating*, and *certification* × *type*. In the table, no financial bonds are rated AA+; no corporates bonds or corporates bonds issued by central enterprises, SOEs, and SCEs are rated AA; and third parties certify no corporate bonds issued by central enterprises, SOEs, or SCEs.

Table 15 in Appendix E lists regression results concerning the interaction variable, *rating* × *type*. This model confirms that financials and corporates bonds rated AAA can lead to a more negative green bond premium, while the ZTDs factor can increase green bond premium (increasing the cost of issuing green bonds). A new finding is that financial bonds rated AA may slightly decrease the green bond premium (decreasing the cost of issuing green bonds).

Table 16 in Appendix E presents regression results of models, including the interaction variables of *certification* × *rating* and

[3] https://www.climatebonds.net/certification

Table 18
Regression results of first-layer models (global green bond market).

	(1)	(2)	(3)	(4)
	Within Regression	Adjust for Autocorrelation	Adjust for Heteroskedasticity	Adjust for Autocorrelation and Heteroskedasticity
ΔLiqSpread	0.320***	−0.027***	−0.492***	−0.209***
	(0.010)	(0.007)	(0.010)	(0.003)
_cons	0.122***	0.117***	0.057***	0.012***
	(0.001)	(0.017)	(0.000)	(0.001)
Obs.	90,543	90,543	90,543	90,543
Pseudo R^2	0.012			

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

Table 19
Descriptive statistics of the green bond premium (global green bond market).

Variable	Mean	Std. Dev.	Min	25% Percentile	50% Percentile	75% Percentile	Max
GP	**0.125**	0.553	−0.757	3.138	**−0.246**	3.107	3.138

Table 20
Descriptive statistics of potential effective factors for the green bond premium (global green bond market).

Variables	Mean	Std. Dev.	Min	Max
GreenCert2	0.836	0.37	0	1
AAA	0.328	0.47	0	1
AAplus	0.048	0.215	0	1
AA	0.088	0.283	0	1
AAminus	0.091	0.288	0	1
Aplus	0.096	0.294	0	1
A	0.09	0.286	0	1
Aminus	0.045	0.207	0	1
BBBplus	0.033	0.179	0	1
BBB	0.022	0.147	0	1
Financials2	0.749	0.434	0	1
Government	0.088	0.283	0	1
Industrials	0.046	0.209	0	1
Utilities	0.063	0.244	0	1
Energy	0.015	0.122	0	1
RealEstate	0.031	0.174	0	1
ConsumerDiscretionary	**0.008**	0.088	0	1
USD	0.218	0.413	0	1
EUR	0.325	0.468	0	1
CNY	0.12	0.325	0	1
SEK	0.173	0.378	0	1
Maturity	6.278	3.967	2	30
ZTDperc	0.001	0.015	0	0.285
LgIssueAmtUSD	8.627	0.374	7.666	9.544

certification × *type*. Model (1) highlights that AAA-rated certified green bonds can have negative green premia compared with their conventional counterparts, while in Table 16, the green certification increases the green bond premium significantly.

4.2.2. Global market

In the global bond market, 145 green bonds are matched to 258 qualified conventional bonds; the number of the conventional bonds less than double of green bonds as some of the conventional ones are matched to more than one green bond. Excluding days without trading data, a one-year period generates 90,543 observations. Table 17 shows descriptive statistics for the dependent and independent variables of the first-layer model for the global market. Green bonds are priced 0.12% higher in ask yield on average than their conventional peers. The −0.006% mean of Δ*LiqSpread* reveals that green bonds' bid-ask yields are slightly lower than those of conventional bonds on average. Compared with the Chinese domestic market, the global market data naturally have a higher standard deviation and fluctuate on a broader range because of the diversity of various markets around the world. Table 18 indicates the same conflict as in Table 9: green bonds are more tightly traded with higher financing costs compared to conventional bonds.

Table 18 shows four regression results under different conditions. The independent variable is significant in all models, suggesting that the liquidity spread difference significantly influences the ask–yield spread. The Wooldridge and Wald tests show that the original model within the regression model has first-order autocorrelation and heteroskedasticity; thus, adjustments are made in the latter three models. Surprisingly, the coefficient of $\Delta LiqSpread$ is negative after adjustment, indicating that less liquid green bonds are priced with lower ask yields than their conventional peers. This conflicts with normal financial theories where more illiquid bonds should trade in a higher yield and a lower price, but accords with the descriptive statistics in Table 18. This study conducted a Wald test to confirm the existence of the time-variant fixed effect.

As Table 19 shows, although the 50% percentile is below zero, the mean of the green bond premium is 0.125%, significantly above zero, indicating that although a more significant number of green bonds might have a negative green bond premium, green bonds with positive green bond premia might have larger premia in absolute value.

Independent variables to be included in the seconder-layer model are listed in Table 21. The mean of ***ConsumerDiscretionary*** is 0.008 (marked in bold font in Table 20), approximately zero, indicating that a very small number of observations are classified as consumer discretionary; thus, this variable was excluded in later regressions.

Table 21 in Appendix E is the correlation matrix of the independent variables. Three industry dummy variables, *Utilities*, *Energy*, and *RealEstate*, have relatively high correlations with other variables. Considering the data in Tables 22 and 23, the study finds that dummy variables *Energy* and *RealEstate* have smaller means and higher correlation coefficients, which may cause collinearity problems in later regressions. To validate this assumption, other information on bonds classified as *Energy* or *RealEstate* was checked. These bonds are issued by Swedish or Chinese issuers mostly in SEK or CNY. Therefore, the two variables could cause collinearity with other existing variables and should be excluded.

Both the Breusch-Pagan and White tests indicate the existence of heteroskedasticity. Thus, the models are regressed with White robust standard error estimation. Table 22 in Appendix E lists VIFs of the independent variables to be included in the models; there is no sign of significant multicollinearity.

Global market main model results: Table 23 in Appendix E specifies the regression results. In all models, the green certification could lead to, at least, **1** bp and, at most, **13.4** bps in the green bond premium, resulting in higher financing costs for green bond issuers compared with conventional bond issuers. Green bonds could have higher ask yield than their conventional peers because they are rated AAA, because bonds rated AAA are of exceptionally high quality, and any further certifications or ratings could barely improve their quality but only to raise the financing cost. By contrast, bonds rated BBB has a negative green bond premium. This means that, regarding green-bonds-rated BBB, a green certification can effectively decrease the financing cost. In the full model, all four bond industry variables have negative influences on the green bond premium. However, when regressed separately, only financial and utility bonds result in a negative green bond premium. Regarding currency character, bonds issued in USD and EUR have a positive premium, meaning it might cost more to issue green bonds in USD or EUR; issuing bonds in CNY might lower the green bonds' issuance cost. Negative coefficients of the maturity and logarithm of the amount issued imply that green bonds with longer maturity and more massive amounts have lower ask yield than their comparable conventional bonds.

Further test: as done in the Chinese market model, the study tests for interaction effects to see if there are specific groups of certified green bonds with a negative green bond premium. Variables including *Certification* × *Bond Rating* and *Certification* × *Industry* are created for the test. Descriptive statistics of the interaction variables are listed in Table 24 of **Appendix E**.

Table 25 in Appendix E shows regression results for certified green bonds with different credit ratings. The AAA-rated certified green bond increases the green bond premium, while certified bonds rated AA+, A+, BBB+, and BBB negatively affect the premium.

Table 26 in Appendix E shows regression results regarding the certified green bonds in different industries. There is no clear and distinct results of whether industry factor could affect green bond financing cost.

5. Conclusions

This study studies whether green bonds are priced lower than conventional bonds—whether negative green bond premiums exist in the Chinese and global bond markets. First, it conducted an event study to conclude that the first-time issuance of green bonds reduces issuers' stock market performance while offering seasoned green bonds does not influence stock market performance. Therefore, Hypothesis 1 is rejected. The study then employed the matching method to construct comparable groups of green and conventional bonds to assess the green bond premium between the two types of bonds. Using a two-layer regression method, the study distinguished the green bond premium from the liquidity spread. Moreover, the study analysed the Chinese and global bond markets. The green bond premium's mean was found to be above zero in both markets, indicating no significant negative green bond premium. The second-layer regression model shows that green certification has a significant positive influence on the green bond premium, meaning that green certification can increase green bonds' financing cost.

In the Chinese bond market, an AAA rating reduces the green bond premium, while, through interaction effects, only AAA-rated green-certified bonds negatively affect the green bond premium, indicating a reduction effect on financing cost. Except for bond maturity, all variables in Hypothesis 2 are significant in Chinese bond market models.

In the global bond market, the AAA (BBB) rating increases (effectively reduces) the green bond premium. Issuing a green bond in USD, EUR, and CNY can impose different levels of significant influences on the green bond premium. Meanwhile, issuing green bonds in CNY (USD and EUR) can reduce (increase) the green bond premium and, thus, decrease (increase) the (debt) financing cost of issuers.

The research reveals that under current circumstances, the cost of green certification can make the pricing of green bonds more expensive than their conventional counterparts; therefore, it is highly possible that issuers would choose to issue conventional bonds to finance their qualified green projects, which is not beneficial for the scale-up of the green bond market. Especially for green projects serving carbon neutrality goals, there would be a lacking in disclosure of carbon offsetting and use of proceeds, making it hard for the regulators to monitor the carbon offset effects of the green projects. To address the issue, governments could give green certification subsidies to green bond issuers. In contrast, green certification service providers could establish a tiered pricing structure based on issuing amount, allowing more small-amount issuers to get involved. From the information disclosure angle, policy makers and sectoral experts could cooperate to set up quantified and universally recognized standards on measuring and disclosing emission reduction data of the projects financed by the green bonds. Tax-based incentives are an important type of policy incentive that this paper suggests regulators to consider. For the investor (demand) side, policymakers could allow tax-exempt green bond issuances, so that investors do not have to pay income tax for the interests they receive from holding green bonds; existing examples include a US tax-exempt green bond issuance financing wind projects in Brazil,[4] a US investment tax credit for solar energy (Azhgaliyeva et al., 2018; Sachs et al., 2019) and a tax-free bond issued by the Indian Renewable Energy Development Agency Limited (IREDA) in 2016 (Agliardi and Agliardi, 2019). From the issuer (supply) side, policymakers could impose a lower tax rate for incomes generated from green projects financed by the green bonds. In this way, tax incentive, as an effective fiscal policy, could stimulate both the demand and supply side of the green bond market.

The primary limitation of this research is that the data are collated from various databases; thus, the data's integrity is not guaranteed. Many green bonds were dropped during the matching and transition process from bond ID to equity ID in the event study because there were no corresponding and comparable conventional bonds.

Further studies could possibly focus on the following aspects: including financial statement data and public sentiment information to estimate the default rate of green bonds, including investors preference to the green bond pricing models, which should be an innovative interaction between behavioural finance and sustainable finance, and pricing mechanism of green sovereign bonds and green municipal bonds, which are important long-term debt tools for the governments and MDBs to support large green infrastructures.

Funding

No Funding acquisition is needed in the project.

CRediT authorship contribution statement

Odile Y. Wu: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

Appendix A. Further details on data source

A-1 Chinese green bond Dataset

To closely examine the Chinese green bond market, this study employed data from Wind in combination with the green bond ID information from the online green bond database at China Financial Information website All Chinese green bonds were added to the initial bond population since the first Chinese green bond was issued in 2016. This study employed June 30, 2019, as the end of the observation period, as of which, there are 426 green bonds of the seven types. Thomson Reuters was employed to source the bond quotation data and corresponding conventional bonds.

A-2 Global green bond Dataset

For the global green bond market, the database is based on a combination of CBI's Labelled Green Bonds Data module, Bloomberg and Thomson Reuters, except for which non-Bloomberg-verified bonds are also included, since previous studies mention that there are green bonds certified by other third parties but not Bloomberg. Green bonds included in the research are either certified as green by third parties (including Bloomberg) or in their own statements. This study employed green bonds issued from March 2, 2010 (date of the earliest issue documented in Bloomberg), to June 30, 2019, during which period 148 out of 1506 had already expired. ORBIS database was used for the event study.

Appendix B. Further details on data exclusion

B-1 Chinese green bond Dataset

As Tang and Zhang (2019) and Hachenberg and Schiereck (2018) suggest, the study first excludes 43 green ABSs, as they are not comparable to normal green bonds due to the different structures. 21 green bonds issued in overseas markets by Chinese entities are excluded as they are issued in multiple currencies and even in multiple markets and there are rare conventional bonds matched with them. 6 green panda bonds are excluded because foreign issuers' financial characteristics are different from those of Chinese entities and could give rise to biases in the model. Thus, the number of Chinese green bonds decreased to 354.

[4] See https://www.climatebonds.net/policy/policy-areas/tax-incentives and also a list of tax-exempt green bonds issued in the US market https://www.sustainableinvest.com/tax-exempt-transactions-leads-green-bond-issuance/

Further, the study excluded bonds that had already expired, would expire within a year or have no outstanding amount. Hachenberg and Schiereck (2018) focus on the liquidity problem and suggest the removal of green bonds issued in relatively small amounts; regarding the Chinese market, the study only includes green bonds with issue amounts that equal or exceed CNY 500 million. The study employed daily bond quotation data as done by Schmitt (2017), and removed 56 green bonds issued within one year. The final Chinese green bond population would then be 146 bonds issued from the start of 2016 to the end of June 2018, with an issue amount of at least CNY 500 million.

B-2 Global green bond Dataset

The exclusion process for the global green bond market is almost the same as mentioned above. Regarding the asset class, the study employed data in Bloomberg, excluding municipals and certificates. The study set an observation period from February 2010 to June 2019, leading to a whole population of 1506 bonds. Using the same screening methodology mentioned in B-1, the study excluded structured bonds, bonds lacking in data, (nearly) expired bonds, bonds with no outstanding amount, bonds with inadequate quotation data, and bonds with liquidity issues.

Appendix C. Further details on event study

C-1 Sample Selection and Grouping

I set the announcement date as the event date, the data of which are available from Bloomberg. Moreover, the study employs the ORBIS database to find information of all listed green bond issuers. 195 listed companies had issued 459 green bonds as of June 30, 2019. The study divides green bonds into two groups, first-time issued and seasoned-offering bonds, to test whether a second- or multi-time green bond issuance can influence the issuer's stock performance. Bonds from issuers already delisted from the market are excluded because of the incomplete stock price data. Bonds issued before issuers' IPO are excluded for the same reason. Thus, there are 111 green bonds from 72 public-listed issuers in the first-time issued bonds group and 205 green bonds from 53 public-listed issuers in the seasoned-offering group.

C-2 Use of CAPM in the Event Study

According to the CAPM, the study estimates the following:

$$R_{i,t} = \alpha_i + \beta_i \times (R_{m,t} - R_{f,t}) + \varepsilon_{i,t},$$

where $R_{i,\,t}$ is the stock return of the i^{th} company, $R_{m,\,t}$ is the market return, $R_{f,\,t}$ is the risk-free return, and $\varepsilon_{i,\,t}$ is the residual error term.

Since green bonds are from different markets globally, this study employs the daily return of the specific market's major stock index as the market return, and the 10-year treasury bond yield of the market's host country as the risk-free return.

The estimated stock return of the i^{th} company on day t is calculated as

$$\widehat{R}_{i,t} = \widehat{\alpha}_i + \widehat{\beta}_i \times (R_{m,t} - R_{f,t}),$$

where $\widehat{\alpha}_i$ and $\widehat{\beta}_i$ are coefficients estimated by the OLS method.

Then, the abnormal daily return (AR) during the event window is calculated as

$$AR_{i,t} = R_{i,t} - \widehat{R}_{i,t}.$$

The CAR is the sum of all daily ARs during the event window.

C-3 Use of Wilcoxon Signed-rank Test: Non-normality in the FI Categories

As can be seen from Fig. 2, four categories have outliers; although only one category in the first-time-issued group shows the existence of an outlier, the three categories' median was skewed in the respective ranges, indicating that the categories may not be in normality. Thus, Wilcoxon test should be applied instead of *t*-test.

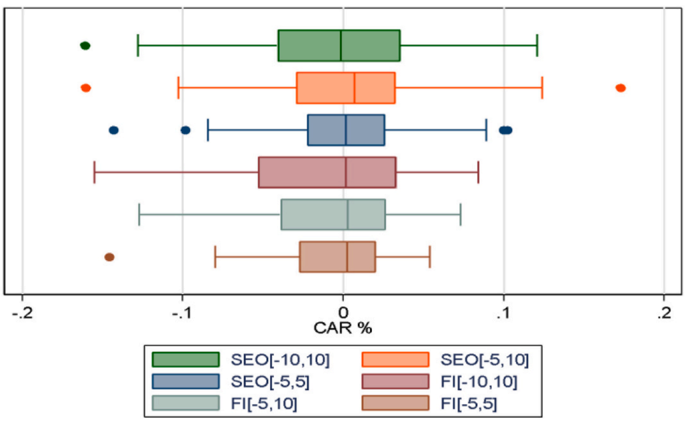

Fig. 2. Boxplot of CAR of seasoned-offering and first-time-issued bonds in three windows.

Fig. 3 shows the histogram of the six categories. The left column (seasoned-offering group) presents a certain level of normality; however, the right column (first-time-issued group) are generally not well distributed and should be tested by Wilcoxon methods.

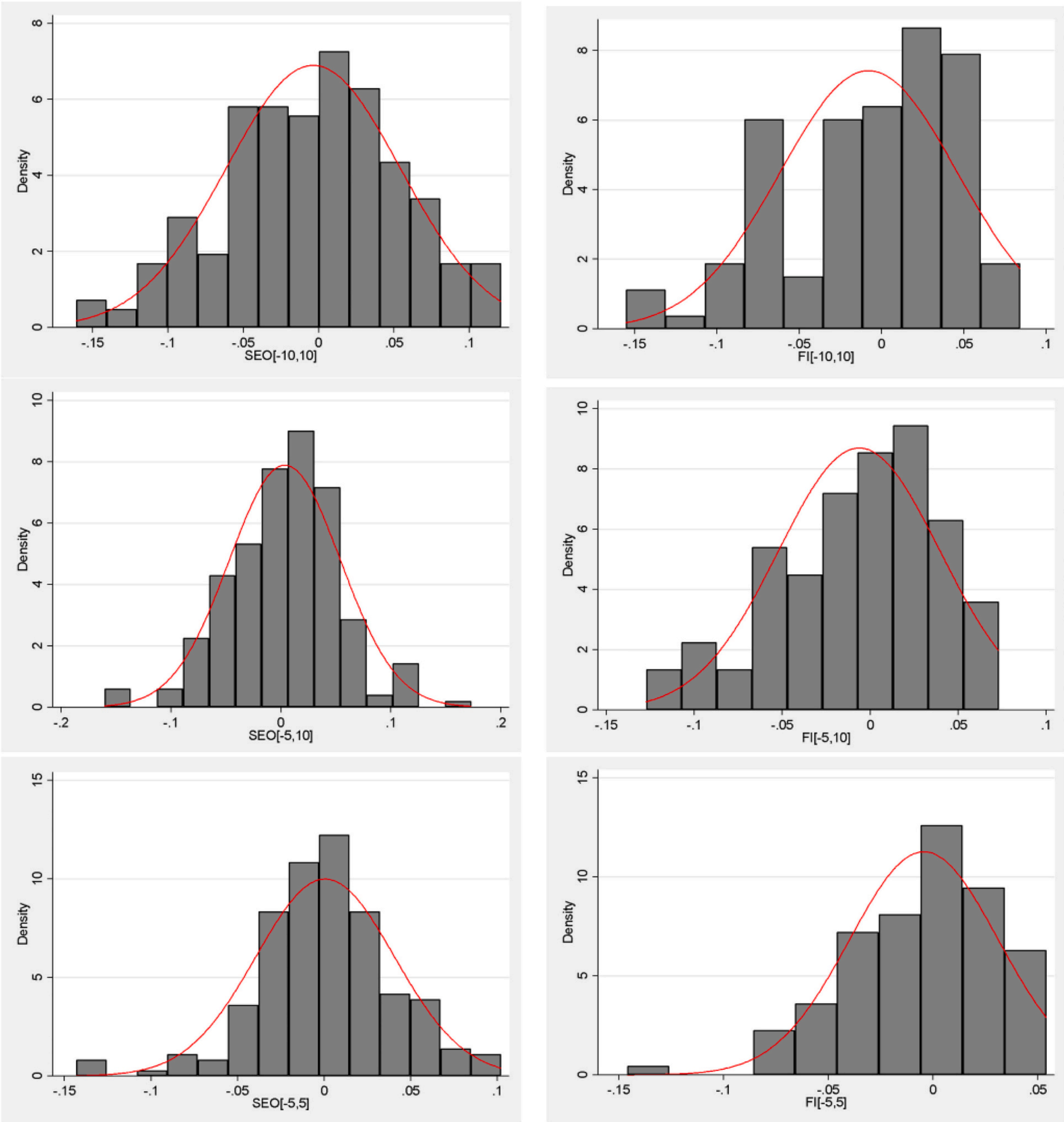

Fig. 3. Histogram of CAR of seasoned-offering and firstp-time-issued bonds in three windows.

Further, an event study was conducted with the beta regressed by a set of 120-day stock trading data to include only very recent market information. The same normality in the seasoned-offering group and non-normality in the first-time-issued group are observed when using the beta regressed by 120-day trading data.

C-4 Further Details on Event Study Results

Table 2 below shows that the CAPM CAR of first-issued green bonds are below 0, contrary to the hypothesis. This result might be related to the investors' estimation of listed companies: when a listed company issues bonds, the investor would like to believe that the company has encountered a crisis and needs extra cash flow. This idea may lead the investor to have a negative view of the company or even panic.

Table 2
Statistical results of CAR using 250-day regressed beta.

	First-time issue			Seasoned offerings		
Event window	[−10,10]	[−5,10]	[−5,5]	[−10,10]	[−5,10]	[−5,5]
CAPM CAR	−0.0078	−0.0063	−0.0044	−0.0036	0.0035	0.0006
				(−0.8976)	(−0.9998)	(−0.2049)
P (T-Test)				0.3705	0.3186	0.8379
P (Wilcoxon Signed-Rank)	0.0000	0.0000	0.0000			

Note: CAPM = capital asset pricing model, CAR = cumulative abnormal returns.

The CAPM CAR results for the six categories are the same when using the 120-day beta in the calculation, except that quantitatively speaking the CAR for all categories are larger than the CAR listed in Table 2.

Appendix D. Appendix

Table 1
Overview of the variables in Eqs. (3), (4), and (5)

Variables	Type	Descriptions
Δy	Quantitative	Ask–yield difference between a green bond and synthetic conventional bond
ΔLiqSpread	Quantitative	Bid–ask spread difference between a green bond and a synthetic conventional bond
GP	Quantitative	Green bond premium, intercept of the first-layer model, and dependent variable of the second-layer model
GreenCert1	Qualitative	Dummy variable, which equals 1 if the bond is verified as green by third-party organizations (in Chinese green bond model)
GreenCert2	Qualitative	Dummy variable, which equals 1 if the bond is verified as green or externally reviewed by third-party organizations (in global green bond model)
AAA	Qualitative	Dummy variable, which equals 1 if the bond is rated AAA or equivalent
AAplus	Qualitative	Dummy variable, which equals 1 if the bond is rated AA+ or equivalent
AA	Qualitative	Dummy variable, which equals 1 if the bond is rated AA or equivalent
AAminus	Qualitative	Dummy variable, which equals 1 if the bond is rated AA- or equivalent
Aplus	Qualitative	Dummy variable, which equals 1 if the bond is rated A+ or equivalent
A	Qualitative	Dummy variable, which equals 1 if the bond is rated A or equivalent
Aminus	Qualitative	Dummy variable, which equals 1 if the bond is rated A- or equivalent
BBBplus	Qualitative	Dummy variable, which equals 1 if the bond is rated BBB+ or equivalent
BBB	Qualitative	Dummy variable, which equals 1 if the bond is rated BBB or equivalent
Corporates	Qualitative	Dummy variable, which equals 1 if the bond is issued by corporates (except central enterprises, state-owned enterprises [SOEs], or state-capitalized enterprises [SCEs]) or is classified as corporates bond under the Wind Bond Classification System, Level 1
CorporatesbyGov	Qualitative	Dummy variable, which equals 1 if the bond is issued by central enterprises, SOEs, or SCEs or classified as central enterprise/SOE/SCE-issued corporates bond under the Wind Bond Classification System, Level 1
Financials1	Qualitative	Dummy variable, which equals 1 if the bond is issued by financial institutions or classified as financial under the Wind Bond Classification System, Level 1 Eq. (5): Dummy variable, which equals 1 if the bond is classified as financial in the Global Industry Classification Standard (GICS), Bloomberg Industry Classification System (BICS), or Thomson Reuters Business Classification (TRBC)
Financials2	Qualitative	Dummy variable, which equals 1 if the bond is classified as financial in the Global Industry Classification Standard (GICS), Bloomberg Industry Classification System (BICS), or Thomson Reuters Business Classification (TRBC)
Government	Qualitative	Dummy variable, which equals 1 if governmental subdivisions issue the bond
Industrials	Qualitative	Dummy variable, which equals 1 if the bond is classified as industrial in GICS, BICS, or TRBC
Utilities	Qualitative	Dummy variable, which equals 1 if the bond is classified as utilities in GICS, BICS, or TRBC
Energy	Qualitative	Dummy variable, which equals 1 if the bond is classified as energy in GICS, BICS, or TRBC
RealEstate	Qualitative	Dummy variable, which equals 1 if the bond is classified as real estate or equivalent in GICS, BICS, or TRBC
ConsumerDiscretionary	Qualitative	Dummy variable, which equals 1 if the bond is classified as consumer discretionary or equivalent in GICS, BICS, or TRBC
USD	Qualitative	Dummy variable, which equals 1 if the bond is issued in USD
EUR	Qualitative	Dummy variable, which equals 1 if the bond is issued in EUR
CNY	Qualitative	Dummy variable, which equals 1 if the bond is issued in CNY

(*continued on next page*)

Table 1 (*continued*)

Variables	Type	Descriptions
SEK	Qualitative	Dummy variable, which equals 1 if the bond is issued in SEK
Maturity	Quantitative	Bond maturity in years
ZTDperc	Quantitative	Proportion of zero-trading days over total trading days
LgIssueAmount	Quantitative	The logarithm of the issue amount of the bonds.
LgIssueAmtUSD	Quantitative	Logarithm of the issue amount of the bonds, in USD

Note: Regarding the green bond rating dummy variables, the study considers bond ratings from S&P and Moody's and Fitch and attributes the lowest rating if more than one organization rates the green bond. The bond industry dummy variables integrate three classification systems: Global Industry Classification Standard (GICS), BICS, and Thomson Reuters Business Classification (TRBC). A government dummy variable is included to identify government-issued bonds. Although these bonds may have an original industry classification, the difference between their pricing and that of other green bonds is uncertain. Thus, this type of bond should be independent of others. Regarding *ZTDperc*, the percentage of ZTDs in one year, the study set different numbers of total trading days for different submarkets of the global market as they have different holiday traditions and days-off. The databases only include the amount issued in the original currency. Thus, regarding *LgIssueAmtUSD*, the logarithm of the amount issued in USD, the study employed the exchange rate on the bond issuance date and converted the issuance amount in local currency into USD. For the second-layer model, several interaction variables are employed for global market research.

Appendix E. Tables and Figures in Section 4

Table 3
Number of different types of green bonds issued in different years (Chinese green bond market).

Panel A: Full Population					
	2016	2017	2018	2019	Total
Financial Bonds	21	42	37	18	118
Corporate Bonds	13	23	30	26	92
Corporate Bonds by Central Enterprises, SOEs, and SCEs	6	36	36	28	106
Green Debt Financing Instruments	8	10	17	11	46
Total	48	111	120	83	362

Panel B: Final Sample				
	2016	2017	2018	Total
Financial Bonds	10	26	27	63
Corporate Bonds	10	13	25	48
Corporate Bonds by Central Enterprises, SOEs, and SCEs	5	35	31	71
Green Debt Financing Instruments	5	6	14	25
Total	30	80	97	207

Table 4
Bond characteristics of the Chinese green bond market.

Full Population	N	Minimum	Maximum	Mean	Std. Deviation
Coupon at Issue %	364	0.5	7.9	4.981566	1.181184454
Bond Term (Year)	364	0.4932	15	4.83652	2.464951601
Issue Amount (100 M) CNY	364	1	300	20.94706	37.42909072
Selected Samples	N	Minimum	Maximum	Mean	Std. Deviation
Coupon at Issue %	207	2.89	7.5	5.032657	1.089284611
Bond Term (Year)	207	3	15	5.347826	2.711855061
Issue Amount (100 M) CNY	207	5	300	23.18691	40.58731574

Table 5
Numbers and types of green bonds issued across years (global green bond market).

Panel A: Full Population				
	Corporate	Financials	Government	Total
1998			1	1

(*continued on next page*)

Table 5 (*continued*)

Panel A: Full Population	Corporate	Financials	Government	Total
2010			7	7
2011			2	2
2012			7	7
2013	2	1	7	10
2014	17	39	54	110
2015	11	35	86	132
2016	39	64	80	183
2017	141	130	76	347
2018	135	224	101	460
2019	72	124	50	246
2020	1			1
Total	418	617	471	1506

Panel B: Final Sample	Corporate	Financials	Government	Total
2012			1	1
2013	1		1	2
2014	5	2	7	14
2015	5	12	27	44
2016	12	24	31	67
2017	35	67	55	157
2018	13	54	32	99
Total	71	159	154	384

Table 6
Bond characteristics of the Global green bond market.

Full Population	N	Minimum	Maximum	Mean	Std. Deviation
Coupon at Issue %	1506	−0.0655	15.5000	2.9345	2.4329
Bond Term (Year)	1506	0.2500	60	6.9142	5.7451
Issue Amount (M) USD	1506	0.0001	22,948.5000	257.0517	785.6304
Selected Samples	N	Minimum	Maximum	Mean	Std. Deviation
Coupon at Issue %	384	0	11.71	2.2299	1.9746
Bond Term (Year)	384	2	31	6.9660	4.3768
Issue Amount (100 M) CNY	384	0.0156	22,948.5000	442.5974	1305.2510

Table 11
Correlation matrix of independent variables (Chinese green bond market).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) *GreenCert1*	1.000									
(2) *AAA*	−0.102	1.000								
(3) *Aaplus*	0.020	−0.354	1.000							
(4) *AA*	0.046	−0.104	−0.029	1.000						
(5) *Financials1*	0.208	−0.085	−0.278	0.105	1.000					
(6) *Corporates*	0.202	0.256	0.051	−0.056	−0.531	1.000				
(7) *CorporatesbyGov*	**−0.606**	0.155	0.102	−0.028	−0.267	−0.182	1.000			
(8) *LgIssueAmount*	−0.096	0.368	−0.316	−0.025	**0.543**	−0.232	0.052	1.000		
(9) *Maturity*	−0.225	0.254	−0.001	−0.086	−0.206	0.214	0.247	0.100	1.000	
(10) *ZTDperc*	**−0.359**	−0.058	0.423	−0.027	−0.262	−0.179	**0.642**	−0.141	0.199	1.000

Table 12
Independent variables VIFs (Chinese green bond market).

	VIF	1/VIF
Financials1	2.897	0.345
CorporatesbyGov	2.612	0.383
ZTDperc	2.302	0.434
Corporates	2.103	0.476

(*continued on next page*)

Table 12 (*continued*)

	VIF	1/VIF
LgIssueAmount	2.073	0.482
GreenCert1	1.763	0.567
AAA	1.668	0.6
Aaplus	1.594	0.627
Maturity	1.241	0.806
AA	1.031	0.97
Mean VIF	1.928	.

Note: VIF = variance inflation factor.

Table 14
Descriptive statistics of cross effects (Chinese green bond market) [Appendix].

Variable	Obs	Mean	Std. Dev.	Min	Max
AAAFinancials1	7773	0.224	0.417	0	1
AAplusFinancials1	7773	0	0	0	0
AAFinancials1	7773	0.008	0.092	0	1
AAACorporates	7773	0.205	0.403	0	1
AAplusCorporates	7773	0.03	0.172	0	1
AACorporates	7773	0	0	0	0
AAACorporatesbyGov	7773	0.068	0.252	0	1
AAplusCorporatesbyGov	7773	0.016	0.124	0	1
AACorporatesbyGov	7773	0	0	0	0
GreenCert1AAA	7773	0.427	0.495	0	1
GreenCert1AAplus	7773	0.074	0.262	0	1
GreenCer1tAA	7773	0.008	0.092	0	1
GreenCert1FInancials	7773	0.392	0.488	0	1
GreenCert1Corporates	7773	0.248	0.432	0	1
GreenCert1CorporatesbyGov	7773	0	0	0	0

Table 15
Regression results of second-layer models with *rating* × *type* cross effects (Chinese green bonds).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GreenPrem	GreenPrem	GreenPrem	GreenPrem	GreenPrem	GreenPrem	GreenPrem	GreenPrem
GreenCert	0.129***	0.125***	0.108***	0.105***	0.138***	0.081***	0.117***	0.108***
	(0.011)	(0.010)	(0.008)	(0.008)	(0.010)	(0.010)	(0.008)	(0.008)
AAAFinancials	−0.035***	−0.035***	−0.012***			−0.057***		
	(0.004)	(0.004)	(0.003)			(0.004)		
AAFinancials	−0.002	−0.007*	−0.004					−0.002
	(0.004)	(0.004)	(0.003)					(0.003)
AAACorporates	−0.067***	−0.059***		−0.046***		−0.086***		
	(0.008)	(0.008)		(0.007)		(0.007)		
AAplusCorporates	0.412***	0.420***		0.426***			0.438***	
	(0.005)	(0.005)		(0.005)			(0.004)	
AAACorporatesbyGov	0.003	0.007			0.042***	−0.136***		
	(0.013)	(0.013)			(0.012)	(0.014)		
AAplusCorporatesbyGov	0.623***	0.621***			0.645***		0.608***	
	(0.017)	(0.017)			(0.017)		(0.010)	
LgIssueAmount	−0.070***	−0.067***	−0.109***	−0.084***	−0.112***	−0.088***	−0.076***	−0.114***
	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
Maturity	0.005***							
	(0.002)							
ZTDperc	0.427***	0.440***	0.735***	0.760***	0.399***	0.779***	0.489***	0.739***
	(0.029)	(0.029)	(0.030)	(0.030)	(0.030)	(0.028)	(0.025)	(0.029)
_cons	0.542***	0.542***	0.937***	0.706***	0.939***	0.804***	0.612***	0.982***
	(0.043)	(0.043)	(0.049)	(0.048)	(0.047)	(0.045)	(0.047)	(0.049)
Obs.	7773	7773	7773	7773	7773	7773	7773	7773
R-squared	0.366	0.366	0.194	0.290	0.268	0.221	0.357	0.194

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

Table 16
Regression results of second-layer model with *certification* × *rating* and *certification* × *type* cross effects (Chinese green bond market).

	(1)	(2)	(3)	(4)
	GreenPrem	GreenPrem	GreenPrem	GreenPrem
GreenCert1AAA	−0.025***			
	(0.005)			
GreenCert1AAplus	0.165***			
	(0.012)			
GreenCert1AA	−0.003			
	(0.004)			
Financials1	0.104***			
	(0.010)			
Corporates	0.158***			
	(0.011)			
CorporatesbyGov	0.087***			
	(0.011)			
LgIssueAmount	−0.120***	−0.085***	−0.088***	−0.088***
	(0.004)	(0.003)	(0.004)	(0.004)
Maturity	−0.007***	0.000	0.000	
	(0.002)	(0.002)	(0.002)	
ZTDperc	0.598***	0.462***	0.459***	0.460***
	(0.030)	(0.024)	(0.024)	(0.023)
GreenCert1Financials		0.053***	0.055***	0.055***
		(0.006)	(0.006)	(0.005)
GreenCert1Corporates		0.083***	0.081***	0.081***
		(0.009)	(0.009)	(0.009)
GreenCert1Corporatesbygov				
AAA		−0.006		
		(0.006)		
AAplus		0.257***	0.261***	0.261***
		(0.013)	(0.012)	(0.012)
AA		0.022***	0.024***	0.024***
		(0.004)	(0.002)	(0.002)
_cons	1.069***	0.752***	0.773***	0.773***
	(0.033)	(0.031)	(0.036)	(0.037)
Obs.	7773	7773	7773	7773
R-squared	0.237	0.256	0.256	0.256

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

Table 21
Correlation matrix of independent variables (global green bond market).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) GreenCert	1.000											
(2) AAA	0.052	1.000										
(3) AAplus	−0.090	−0.158	1.000									
(4) AA	−0.014	−0.216	−0.070	1.000								
(5) AAminus	0.043	−0.221	−0.071	−0.098	1.000							
(6) Aplus	0.092	−0.227	−0.073	−0.101	−0.103	1.000						
(7) A	−0.019	−0.219	−0.071	−0.097	−0.099	−0.102	1.000					
(8) Aminus	0.096	−0.151	−0.049	−0.067	−0.069	−0.070	−0.068	1.000				
(9) BBBplus	−0.043	−0.130	−0.042	−0.057	−0.059	−0.060	−0.058	−0.040	1.000			
(10) BBB	0.067	−0.105	−0.034	−0.047	−0.048	−0.049	−0.047	−0.033	−0.028	1.000		
(11) Financials	0.206	0.216	−0.212	0.000	0.183	0.003	0.046	−0.062	0.001	−0.176	1.000	
(12) Government	0.058	−0.152	0.206	0.107	−0.098	−0.004	−0.097	0.076	−0.058	−0.047	−0.536	1.000
(13) Industrials	0.097	−0.153	−0.049	0.029	−0.070	0.181	−0.069	0.147	−0.041	0.240	−0.379	−0.068
(14) Utilities	−0.293	0.012	−0.059	−0.081	−0.082	−0.085	−0.082	−0.056	0.142	0.195	−0.449	−0.081
(15) Energy	−0.279	−0.086	0.549	−0.038	−0.039	−0.040	−0.039	−0.027	−0.023	−0.019	−0.214	−0.038
(16) RealEstate	−0.019	−0.125	−0.040	−0.056	−0.057	−0.058	0.283	−0.039	−0.033	−0.027	−0.310	−0.056
(17) USD	0.103	0.236	−0.025	−0.093	0.028	−0.011	−0.096	−0.081	0.014	−0.029	0.306	−0.164
(18) EUR	0.260	−0.193	−0.075	0.158	0.027	0.156	0.079	0.196	0.168	0.172	0.114	−0.090
(19) CNY	−0.413	0.237	0.133	0.032	−0.117	−0.120	−0.116	−0.080	−0.068	−0.056	−0.147	−0.114

(*continued on next page*)

Table 21 (*continued*)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(20) SEK	−0.109	−0.143	0.103	−0.142	−0.125	−0.149	0.165	−0.099	−0.085	−0.069	−0.110	0.298
(21) Maturity	0.155	0.014	−0.088	0.293	−0.090	0.017	0.024	−0.041	−0.013	0.038	−0.209	0.210
(22) ZTDperc	0.024	−0.046	−0.019	−0.026	−0.009	0.009	0.003	−0.018	−0.016	−0.013	0.045	−0.020
(23) LgIssueAmtUSD	0.147	0.123	−0.214	−0.100	−0.032	0.023	−0.167	0.026	0.094	0.097	0.084	−0.113

Variables	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
(1) GreenCert											
(2) AAA											
(3) AAplus											
(4) AA											
(5) AAminus											
(6) Aplus											
(7) A											
(8) Aminus											
(9) BBBplus											
(10) BBB											
(11) Financials											
(12) Government											
(13) Industrials	1.000										
(14) Utilities	−0.057	1.000									
(15) Energy	−0.027	−0.032	1.000								
(16) RealEstate	−0.039	−0.047	−0.022	1.000							
(17) USD	−0.116	−0.137	−0.065	−0.095	1.000						
(18) EUR	−0.067	−0.034	−0.086	0.082	−0.366	1.000					
(19) CNY	0.004	0.184	0.335	−0.066	−0.195	−0.256	1.000				
(20) SEK	−0.100	−0.119	−0.057	0.136	−0.242	−0.318	−0.169	1.000			
(21) Maturity	0.100	0.067	−0.102	0.052	−0.139	0.211	−0.195	−0.127	1.000		
(22) ZTDperc	−0.019	−0.022	−0.010	−0.015	0.119	−0.041	−0.031	−0.015	0.038	1.000	
(23) LgIssueAmtUSD	−0.129	0.091	−0.220	0.171	0.073	0.382	−0.123	−0.217	0.030	−0.085	1.000

Table 22
Independent variables VIFs (global green bond market).

	VIF	1/VIF
Financials2	4.910	0.204
EUR	3.480	0.287
AAA	3.120	0.320
Government	3.080	0.325
USD	2.610	0.383
SEK	2.510	0.398
Industrials	2.500	0.400
Utilities	2.460	0.406
AA	2.320	0.431
CNY	2.220	0.450
Aplus	2.120	0.472
AAminus	2.010	0.497
A	1.900	0.527
LgIssueAmtUSD	1.670	0.597
Aminus	1.660	0.602
AAplus	1.610	0.622
GreenCert2	1.520	0.659
Maturity	1.450	0.691
BBB	1.450	0.691
BBBplus	1.430	0.697
ZTDperc	1.080	0.929
Mean VIF	2.240	

Note: VIF = variance inflation factor.

Table 23
Regression results of second-layer models (global green bond market).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
GreenCert2	0.031***	0.030***	0.024***	0.083***	0.023***	0.016***	0.015***	**0.010****	0.088***	**0.134*****	0.020***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.006)	(0.004)
AAA	0.259***	0.252***	0.266***		0.241***	0.230***	0.230***	0.228***	0.198***	0.253***	0.356***
	(0.008)	(0.008)	(0.009)		(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.009)	(0.011)
AAplus	−0.080***	−0.087***			−0.068***	−0.050***	−0.049***	−0.054***	−0.109***	−0.036***	0.004
	(0.010)	(0.007)			(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.005)	(0.005)
AA	0.058***	0.049***			0.031***	0.024***	0.023***	0.019***	0.028***	0.067***	0.104***
	(0.009)	(0.006)			(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)
AAminus	−0.045***	−0.054***			−0.062***	−0.074***	−0.074***	−0.077***	−0.055***	−0.027***	−0.028***
	(0.009)	(0.006)			(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.004)	(0.004)
Aplus	−0.078***	−0.086***			−0.103***	−0.102***	−0.105***	−0.105***	−0.075***	−0.018***	−0.043***
	(0.008)	(0.006)			(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.003)
A	0.014*										
	(0.008)										
Aminus	0.138***	0.129***			0.106***	0.117***	0.113***	0.115***	0.156***	0.197***	0.139***
	(0.011)	(0.009)			(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)
BBBplus	0.016**	0.009*									
	(0.007)	(0.005)									
BBB	−0.052***	−0.057***		−0.095***	−0.102***	−0.071***	−0.079***	−0.061***	−0.016**	0.101***	0.012**
	(0.009)	(0.008)		(0.008)	(0.006)	(0.006)	(0.007)	(0.006)	(0.008)	(0.006)	(0.005)
Financials2	−0.181***	−0.182***	−0.163***	−0.090***	−0.054***				−0.141***	−0.053***	−0.132***
	(0.006)	(0.005)	(0.005)	(0.004)	(0.005)				(0.005)	(0.004)	(0.005)
Government	−0.156***	−0.157***	−0.133***	−0.130***		0.002			−0.133***	−0.163***	−0.208***
	(0.005)	(0.005)	(0.004)	(0.004)		(0.004)			(0.004)	(0.004)	(0.006)
Industrials	−0.152***	−0.156***	−0.136***	−0.155***			0.019***		−0.174***	−0.222***	−0.181***
	(0.008)	(0.007)	(0.005)	(0.006)			(0.006)		(0.008)	(0.007)	(0.008)
Utilities	−0.175***	−0.180***	−0.166***	−0.104***				−0.036***	−0.178***	−0.197***	−0.196***
	(0.005)	(0.005)	(0.004)	(0.005)				(0.004)	(0.004)	(0.005)	(0.004)
USD	0.392***	0.390***	0.383***	0.434***	0.403***	0.385***	0.386***	0.383***	0.392***		
	(0.013)	(0.013)	(0.012)	(0.014)	(0.012)	(0.012)	(0.011)	(0.011)	(0.012)		
EUR	0.062***	0.063***	0.069***	0.017***	0.082***	0.065***	0.067***	0.063***		−0.130***	
	(0.008)	(0.007)	(0.006)	(0.005)	(0.007)	(0.007)	(0.006)	(0.006)		(0.006)	
CNY	−0.164***	−0.167***	−0.164***	−0.028***	−0.148***	−0.144***	−0.145***	−0.141***			−0.326***
	(0.007)	(0.006)	(0.006)	(0.003)	(0.006)	(0.005)	(0.006)	(0.006)			(0.010)
SEK	0.007										
	(0.006)										
Maturity	−0.019***	−0.019***	−0.018***	−0.012***	−0.019***	−0.017***	−0.018***	−0.017***	−0.014***	−0.016***	−0.024***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ZTDperc	−1.110***	−1.137***	−1.121***	−1.716***	−1.165***	−1.207***	−1.202***	−1.212***	−1.246***	0.023	0.226***
	(0.113)	(0.107)	(0.109)	(0.127)	(0.106)	(0.108)	(0.108)	(0.108)	(0.104)	(0.081)	(0.083)
LgIssueAmtUSD	−0.095***	−0.099***	−0.094***	−0.039***	−0.099***	−0.092***	−0.091***	−0.089***	−0.062***	0.014	−0.060***
	(0.014)	(0.012)	(0.012)	(0.011)	(0.012)	(0.012)	(0.012)	(0.012)	(0.010)	(0.012)	(0.011)
_cons	1.036***	1.078***	1.009***	0.466***	0.960***	0.864***	0.859***	0.846***	0.674***	0.014	0.827***
	(0.126)	(0.108)	(0.100)	(0.096)	(0.106)	(0.103)	(0.102)	(0.103)	(0.086)	(0.107)	(0.096)
Obs.	30,905	30,905	30,905	30,905	30,905	30,905	30,905	30,905	30,905	30,905	30,905
R-squared	0.172	0.172	0.165	0.128	0.169	0.167	0.168	0.168	0.163	0.099	0.115

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

Table 24
Descriptive statistics of cross effects (global green bond market).

Variable	Obs	Mean	Std. Dev.	Min	Max
GreenCert2AAA	30,905	0.284	0.451	0	1
GreenCert2AAplus	30,905	0.033	0.179	0	1
GreenCert2AA	30,905	0.072	0.258	0	1
GreenCert2AAminus	30,905	0.081	0.273	0	1
GreenCert2Aplus	30,905	0.09	0.286	0	1
GreenCert2A	30,905	0.073	0.26	0	1
GreenCertt2Aminus	30,905	0.045	0.207	0	1
GreenCert2Bplus	30,905	0.025	0.156	0	1
GreenCert2BBB	30,905	0.022	0.147	0	1
GreenCert2Fin	30,905	0.659	0.474	0	1
GreenCert2Gov	30,905	0.08	0.271	0	1
GreenCert2Ind	30,905	0.046	0.209	0	1
GreenCert2Uti	30,905	0.027	0.161	0	1

Table 25
Regression results of second-layer models with *GreenCert* × *Bond Rating* cross effects (global green bond market).

	(1)	(2)	(3)
GreenCert2AAA	0.280***	0.283***	0.372***
	(0.009)	(0.008)	(0.008)
GreenCert2AAplus	−0.101***	−0.099***	−0.012
	(0.018)	(0.017)	(0.017)
GreenCert2AA	0.024	0.027**	0.079***
	(0.015)	(0.013)	(0.014)
GreenCert2AAminus	−0.021*		0.052***
	(0.013)		(0.012)
GreenCert2Aplus	−0.056***	−0.053***	−0.011
	(0.013)	(0.012)	(0.012)
GreenCert2A	0.013		0.079***
	(0.013)		(0.013)
GreenCert2Aminus	0.140***	0.144***	0.164***
	(0.017)	(0.016)	(0.015)
GreenCert2BBBplus	−0.043**	−0.040**	−0.028
	(0.021)	(0.020)	(0.020)
GreenCert2BBB	−0.080***	−0.078***	0.001
	(0.023)	(0.022)	(0.021)
Financials2	−0.169***	−0.176***	
	(0.014)	(0.014)	
Government	−0.122***	−0.128***	
	(0.018)	(0.018)	
Industrials	−0.129***	−0.136***	
	(0.021)	(0.021)	
Utilities	−0.090***	−0.095***	
	(0.018)	(0.017)	
USD	0.398***	0.396***	
	(0.009)	(0.009)	
EUR	0.070***	0.070***	
	(0.010)	(0.010)	
CNY	−0.102***	−0.102***	
	(0.011)	(0.010)	
Maturity	−0.018***	−0.018***	−0.021***
	(0.001)	(0.001)	(0.001)
ZTDperc	−1.068***	−1.047***	0.503**
	(0.199)	(0.198)	(0.204)
LgIssueAmtUSD	−0.077***	−0.078***	0.000
	(0.009)	(0.009)	(0.008)
_cons	0.881***	0.895***	0.132*
	(0.081)	(0.078)	(0.071)
Obs.	30,905	30,905	30,905
R-squared	0.174	0.174	0.100

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

Table 26
Regression results of second-layer models with *Certification* × *Industry* cross effects (global green bond market).

	(1)	(2)	(3)	(4)
AAA	0.248***	0.245***		
	(0.010)	(0.010)		
Aplus	−0.046***	−0.046***		
	(0.017)	(0.017)		
AA	0.035**	0.034**		
	(0.015)	(0.015)		
AAminus	−0.057***	−0.059***		
	(0.013)	(0.013)		
Aplus	−0.094***	−0.095***		
	(0.014)	(0.014)		
A	0.034**	0.035**		
	(0.014)	(0.014)		
Aminus	0.120***	0.119***		
	(0.018)	(0.018)		
BBBplus	−0.022	−0.021		
	(0.019)	(0.019)		
BBB	−0.093***	−0.093***		
	(0.024)	(0.024)		
GreenCert2Fin2	−0.009		0.158***	0.159***
	(0.009)		(0.008)	(0.007)
GreenCert2Gov	0.030**	0.036***	0.007	
	(0.014)	(0.013)	(0.014)	
GreenCert2Ind	0.034**	0.040**	−0.042**	−0.041***
	(0.017)	(0.016)	(0.016)	(0.016)
GreenCert2Uti	0.050**	0.056***	−0.029	
	(0.021)	(0.021)	(0.021)	
USD	0.396***	0.395***		
	(0.010)	(0.010)		
EUR	0.076***	0.074***		
	(0.011)	(0.010)		
CNY	−0.147***	−0.144***		
	(0.012)	(0.011)		
Maturity	−0.018***	−0.018***	−0.016***	−0.016***
	(0.001)	(0.001)	(0.001)	(0.001)
ZTDperc	−1.136***	−1.144***	−0.332	−0.335
	(0.201)	(0.201)	(0.210)	(0.210)
LgIssueAmtUSD	−0.088***	−0.087***	0.003	0.001
	(0.010)	(0.010)	(0.008)	(0.008)
_cons	0.835***	0.822***	0.100	0.114
	(0.087)	(0.086)	(0.073)	(0.072)
Obs.	30,905	30,905	30,905	30,905
R-squared	0.168	0.168	0.037	0.037

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

Appendix F. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ememar.2022.100909.

References

Agliardi, E., Agliardi, R., 2019. Financing environmentally-sustainable projects with green bonds. Environ. Dev. Econ. 24 (6), 608–623. https://doi.org/10.1017/S1355770X19000020.
Azhgaliyeva, D., Kapsaplyamova, Z., Low, L., 2018. Implications of fiscal and financial policies for unlocking green finance and green investment (No. 861). ADBI Working Paper.
Bachelet, M.J., Becchetti, L., Manfredonia, S., 2019. The green bonds premium puzzle: the role of issuer characteristics and third-party verification. Sustainability. 11, 1–22. https://doi.org/10.3390/su11041098.
Bakshi, A., Preclaw, R., 2015. The Cost of Being Green, Baraclays Credit Research.
Carney, M., 2015. Breaking the Tragedy of the Horizon – Climate Change and Financial Stability [WWW Document]. URL. www.bankofengland.co.uk/publications/Pages/speeches/default.aspx.
Ehlers, T., Packer, F., 2016. Green Bonds – Certification, Shades of Green and Environmental Risks. Bank for International Settlements, Basel.
Flammer, C., 2018. Corporate green bonds. Acad. Manag. Proc. 2019 (1), 15250. https://doi.org/10.5465/ambpp.2019.15250abstract.
Hachenberg, B., Schiereck, D., 2018. Are green bonds priced differently from conventional bonds? J. Asset Manag. 19, 371–383. https://doi.org/10.1057/s41260-018-0088-5.
Harrison, C., Muething, L., 2021. Sustainable Global State of the Market 2020.

ICMA, 2018. Green Bond Principles. https://www.icmagroup.org/green-social-and-sustainability-bonds/green-bond-principles-gbp/ (accessed 16 Feb 2020).

Karpf, A., Mandel, A., 2017. Does it pay to be green? A comparative study of the yield term structure of green and Brown bonds in the US municipal bonds market. SSRN Electron. J. https://doi.org/10.2139/ssrn.2923484.

Kochetygova, J., Jauhari, A., 2014. Climate Change, Green Bonds, and Index Investing : The New Frontier. S&P Dow Jones Indices LLC, pp. 1–15.

Löffler, K.U., Petreski, A., Andreas, S., 2021. Drivers of Green Bond Issuance and New Evidence on the “Greenium”. Eur. Econ. Rev. 11, 1–24. https://doi.org/10.1007/s40822-020-00165-y.

Loomis & Sayles, 2020. Beyond the label: An Assessment of the Green Bond Market. https://www.im.natixis.com/en-hk/resources/beyond-the-label-an-assessment-of-the-green-bond-market (accessed 27 Aug 2020).

MacAskill, S., Roca, E., Liu, B., Stewart, R.A., Sahin, O., 2021. Is there a green premium in the green bond market? Systematic literature review revealing premium determinants. J. Clean. Prod. 280, 124491 https://doi.org/10.1016/j.jclepro.2020.124491.

Nanayakkara, M., Colombage, S., 2019. Do investors in green bond market pay a premium? Global evidence. Appl. Econ. 51, 4425–4437. https://doi.org/10.1080/00036846.2019.1591611.

Nordhaus, W.D., 1975. Can we control carbon dioxide?. In: IIASA Working Paper. Laxenburg, Austria.

Nordhaus, W.D., 1992. An optimal transition path for controlling greenhouse gases. Science (80-.) 258, 1315–1319.

Nordhaus, W.D., 1994. Managing the Global Commons : The Economics of Climate Change. MIT Press, Cambridge, Mass.

Nordhaus, W.D., 2019. Climate change: the ultimate challenge for economics. The Nobel Prizes. 439–466.

Ntsama, Y.U.O., Yan, C., Nasiri, A., Mboungam, H.A.M., 2021. Green bonds issuance : insights in low- and middle-income countries. Int. J. Corp. Soc. Responsib. 6 https://doi.org/10.1186/s40991-020-00056-0.

Reboredo, J.C., 2018. Green bond and financial markets: co-movement, diversification and price spillover effects. Energy Econ. 74, 38–50. https://doi.org/10.1016/j.eneco.2018.05.030.

Reichelt, H., 2010. Green Bonds: A Model to Mobilise Private Capital to Fund Climate Change Mitigation and Adaptation Projects: Climate Change Is a Problem of Global Proportions. World Bank, Washington, DC.

Sachs, J.D., Woo, W.T., Yoshino, N., Taghizadeh-Hesary, F., 2019. Why is Green Finance Important? (No. 917), ADBI Working Paper.

Schmitt, S.J., 2017. A Parametric Approach to Estimate the Green Bond Premium. http://dspace.insper.edu.br/xmlui/bitstream/handle/11224/2253/STEPHANJAKOBSCHMITT_Trabalho.pdf?sequence=1 (accessed 16 Feb 2020).

Stern, N.H., Great Britain. Treasury, 2005. The Economics of Climate Change : The Stern Review. https://doi.org/10.1017/CBO9780511817434.

Tang, D.Y., Zhang, Y., 2019. Do shareholders benefit from green bonds? J. Corp. Finan. 1–18. https://doi.org/10.1016/j.jcorpfin.2018.12.001.

Wulandari, F., Schhfer, D., Andreas, S., Sun, C., Febi, W., Dorothea, S., Andreas, S., Suna, C., 2018. Liquidity risk and yield spreads of green bonds. SSRN Electron. J. https://doi.org/10.2139/ssrn.3161323.

Zerbib, O.D., 2019. The effect of pro-environmental preferences on bond prices: evidence from green bonds. J. Bank. Financ. 98, 39–60. https://doi.org/10.1016/j.jbankfin.2018.10.012.