How effectively do green bonds help the environment?

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Abstract

We examine whether the magnitude of financial benefits derived from corporate green bond issuance is associated with the magnitude of future reductions in carbon emissions of non-financial corporates. We find a significantly negative relationship between the volume of issued green bonds and future carbon intensity; this relationship is limited to firms with higher financial constraints and higher credit risk. An association between pricing advantages of green bonds and future carbon reductions is present in some specifications. The findings suggest that green bonds can help firms finance carbon reductions, but they also indicate that a considerable fraction of green bond financing does not exert direct effects.

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1. Introduction

The decarbonization needed to limit climate change requires considerable investments. An estimate of the energy transition investments needed to reach the 1.5 degree climate goal is USD 131 trillion by 2050 (IRENA, 2021), corresponding to an annual average of more than USD 4 trillion. Green bonds, a financial innovation of recent years, could help provide significant capital for these investments. Green bonds are issued to finance projects whose proceeds are used to support the environment and reduce global warming. Issuance was more than USD 500 billion in 2021 and is projected to surpass USD 1 trillion in 2023.[1]

A comparison of aggregate financing volumes with investment needs, however, is insufficient to determine whether financial markets provide an effective contribution to climate change mitigation. Investment projects are likely to differ in their carbon-reduction efficiency. Also, issuers may differ in their ability to raise funds for climate-related projects. As a consequence, a dollar provided through green bonds can yield a very different environmental return depending on the issuer to which it is provided. Aggregate carbon reduction can be accelerated, and its cost can be reduced, if financial markets allocate more or cheaper funding to projects with large environmental benefits and that otherwise would not be realized. Money and valuable time will be lost if financial markets allocate funds in an indiscriminate manner. Viewed from the perspective of investors, the question is whether green bonds really provide the measurable impact investors are looking for and that has been promised to them.[2]

In the present paper, we examine whether financial markets allocate green funds in an effective or indiscriminate manner. We do so by studying whether the magnitude of financial benefits derived from corporate green bond issuance is associated with the magnitude of future reductions in corporate carbon emissions. We consider two measures of financial benefits: (i) issuer-level green bond volume; and (ii) pricing advantages from issuing bonds with a greenium, i.e., at rates lower than the rates of non-green bonds.

For a comprehensive, international sample of non-financial corporates, we find that higher green bond issue volumes predict future carbon reductions. Though the findings are consistent

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[1] Based on information from the Climate Bonds Initiative. See https://www.climatebonds.net/2022/01/500bn-green-issuance-2021-social-and-sustainable-acceleration-annual-green-1tn-sight-market

[2] As for asset managers' promises, see, for example, the following reason listed by iShares for investing in its Global Green Bond ETF: "Pursue a measurable environmental impact from your investment." (https://www.ishares.com/us/literature/fact-sheet/bgrn-ishares-global-green-bond-etf-fund-fact-sheet-en-us.pdf) As for investor preferences, see, for example, the following World Bank assessment: "We see that more investors also want to put their money to have a positive and measurable impact on society" (https://www.worldbank.org/en/news/immersive-story/2019/03/18/10-years-of-green-bonds-creating-the-blueprint-for-sustainability-across-capital-markets).

with impact or additionality, i.e., with green bonds directly affecting a firm's ability to reduce carbon emissions, we hasten to add that our regression results cannot establish the existence of such direct effects. However, two additional observations are consistent with direct effects being in play. First, for many firms, green bond issue volumes relative to carbon emissions are so large that using the proceeds for carbon mitigation would impact a firm's carbon emissions significantly. Second, the association between issue volumes and carbon reductions is visible only among firms that are financially constrained or that have an above-average credit risk. For this subset of firms, the alternative targeted financing option that green bonds offer is likely to be more valuable when compared with other firms.

Another financial benefit from green bond issuance that we study is pricing advantages, which we measure as the cumulated dollar advantages from issuing green bonds at a yield different from the yield of a matched non-green bond of the same issuer. We find some evidence of a relationship between pricing advantages and carbon reductions, but the evidence is weaker than for issue volumes in that regression results are not stable across variations. Furthermore, we observe that the pricing advantage's size is very small relative to carbon emissions, even in the top quartile of pricing advantages.

The extant literature has focused on the question of whether environmental performance changes after a firm has issued green bonds. Flammer (2020, 2021) and Fatica and Panzica (2021) find that carbon emissions decline after green bond issuance. The authors favor a signaling interpretation. Issuance of green bonds is associated with higher administrative and compliance costs; because of these costs, issuers can credibly signal their commitment toward the environment. On a related note, one can argue that green bond issue activity helps strengthen internal commitment to climate action, which is a frequently mentioned benefit of green bond issue activity (Sangiorgi and Schopohl, 2021). In such interpretations, green bonds are beneficial because they provide a signaling or commitment device, not because they allocate funds to green projects.

In our study, we also find that the decision to issue green bonds precedes carbon reductions, but that this association's magnitude declines once we control for the financial benefits from green bond issuance. We find that having an above-average issue volume is a stronger predictor of carbon reductions than being a green bond issuer.

Therefore, our study indicates that the green bond market has the potential to help the environment by allocating funds to firms that can use them to lower carbon emissions. However, it also suggests that market participants should not rely on it. For firms with a low credit risk and low financial constraints, we fail to find a significant relationship between green bond issue volumes and carbon reductions. Thus, there is no reliable evidence that the provision of incremental green financing to such firms makes a difference.

Empirical studies on corporate green bonds that are related most closely to our work have already been cited. For a comprehensive sample of green bonds, Zerbib (2019) documents a small average greenium of 2 basis points. Karpf and Mandel (2018) and Larcker and Watts (2020) study the greenium in municipal bonds. Hachenberg and Schiereck (2018) and Kapraun et al. (2021) provide additional evidence concerning the greenium and its cross-sectional determinants. Bongaerts and Schoenmaker (2020) propose changes in the design of green financing. Daubanes, Mitali and Rochet (2021) present a theoretical analysis of green bond signaling and manager incentives.

The remainder of this study proceeds as follows. Section 2 describes the data sources and methodology. Section 3 presents the empirical results. Section 4 concludes the paper.

2. Data and methodology

Data sources and construction

We collect information on green bond issues from the following three sources: the Environmental Finance Bond Database (EFBD); Climate Bond Initiative (CBI); and Refinitiv Green Bond Guide. We merge the data by starting with bond issues contained in the EFBD. Then we add bond issues from the CBI that are not included in the EFBD, before we add issues from Refinitiv that are not included in the other two databases. We limit the sample to non-financial corporates.[3] The information in the green bond lists is complemented by additional bond-specific information, such as issue yields, which we obtain from Refinitiv (Datastream and Eikon). We downloaded the green bond information in 2021, meaning that the last year for which we have complete information on green bond issuance is 2020.

Financial and environmental data of bond issuers are obtained from Datastream. There is no information on private firms in Datastream, but considering that some of the variables we use for our analysis require market values of equity, the effective sample size would not increase if we collected data on private firms from other sources. We match the bond issuers stated in the

[3] To select non-financial corporates, we choose the issuer type "Corporate" in the EFBD, the issuer type "Non-financial corporate" in the CBI database, and the issuer type "Corporates" ex-issuers from the TRBC sector "Financials" in the Refinitiv database. Furthermore, we exclude firms with SIC codes starting with 6.

green bond databases to the Datastream issuer codes based on issuer names and the parent company information available in Eikon. If a bond issuer does not have listed equity, we match the bond to the parent company that Eikon states for the bond issuer, provided that it is listed.

Control firms that have not issued green bonds are chosen from the universe of firms in the ASSET4 database of Refinitiv. Since these control firms are used for regressions that require information on variables from the ASSET4 database, the ASSET4 universe provides a complete set of possible candidates for matching and control.

Our key variable of interest, CO2 emissions per firm, is measured on a fiscal year basis. We therefore construct a yearly panel based on fiscal years. Green bond issues also are allocated to fiscal years. For example, if a firm with a fiscal year end in September issued a green bond in November 2019, the green bond will be allocated to the fiscal year 2020.

For the definition of time fixed effects, observations with fiscal year ends from January to May are allocated to the previous year's group. Note that for the sake of brevity, we henceforth will refer to *years* instead of *fiscal years* when we refer to a time period in the panel data set.

Variable definitions

Our core measure of environmental performance is *CarbonIntensity*, which we define as estimated Scope 1 and Scope 2 greenhouse gas emissions, measured as metric tons of CO2 equivalents, divided by revenue (in USD millions). For the sake of brevity, we henceforth will simply refer to *carbon* or *CO2 emissions* instead of *CO2-equivalent emissions*.

Scaling carbon emissions by revenue is common in the financial industry[4] and in academic studies.[5] It appears adequate because both variables are related to a firm's production level. As part of our sensitivity analysis, we will consider scaling CO2 emissions by total assets. Furthermore, we will consider environmental ratings as an alternative measure of environmental performance.

[4] For example, scaling by revenue is used by the index providers FTSE (https://research.ftserussell.com/products/downloads/ftse-global-climate-index-series.pdf), MSCI (https://www.msci.com/index-carbon-footprint-metrics), and Standard & Poor's (https://www.spglobal.com/spdji/en/documents/additional-material/spdji-esg-carbon-metrics.pdf).

[5] See, for example, Bolton and Kacperczyk (2021), Pedersen, Fitzgibbons and Pomorski (2021), and Shive and Forster (2020).

To determine matching firms with no green bond issuance, we follow Flammer (2021) and use the following variables for the selection of nearest neighbors: $Leverage$ (total debt divided by the book value of assets); ROA (return on assets); $Size$ (the natural logarithm of the book value of total assets in USD); $TobinQ$ (market value of total assets divided by the book value of total assets); and the three components of the Refinitiv ESG rating: the environmental score, the social score, and the governance score.

To capture green bond issuance activity, we first follow Flammer (2021) and define the following dummy variables: $GreenBond_{i,t}$ takes the value one if firm i has issued a green bond by year t, and zero otherwise. Lagging this variable by two years leads to what is called "Green bond (long-term, 2+ years)" by Flammer (2021). $FirstGreenBond_{i,t}$ takes the value one if a firm issued its first green bond in year t. $FirstGreenBond_{i,t-1}$ is equal to what Flammer calls "Green bond (short term, 1 year)."

To capture potential effects related to the green bond issuance's purpose, we use information from the EFBD and Refinitiv green bond databases.[6] We classify a bond issue as climate-related if it meets one of the following requirements: According to EFBD, proceeds are used for green buildings, climate, energy efficiency, or renewable energy, or the use of proceeds according to Refinitiv is related similarly to a reduction in CO2 emissions.[7] For such climate-related bond issues, we define the same set of dummy variables as for green bonds in general. For example, $ClimateGreenBond_{i,t}$ equals one if a firm has issued a climate-related green bond by year t.

Next, we define a set of variables that aim to capture the magnitude of a firm's green bond financing. $OutVolume_{i,t}$ is the volume of a firm's green bonds outstanding at the end of year t, scaled by the firm's revenue in year t. For an easier presentation of descriptive statistics and estimates, we multiply the variable by 1,000. $HighOutVolume_{i,t}$ is a dummy variable that takes the value of one if $OutVolume_{i,t}$ is above the median $OutVolume$ of the issuers that in the respective year have a non-zero outstanding green bond volume. The two variables are also defined for the subset of climate-related bonds. For example, $ClimateOutVolume_{i,t}$ is the outstanding volume of the climate-related bonds issued by firm i.

[6] We do not use the CBI classification because it appears to be too coarse for meaningful identification of climate-related bond issues.

[7] We take the following purposes to be climate-related: alternative energy; carbon reduction through reforestation and avoided deforestation; electric and public power; energy efficiency; funding new technologies to reduce GHS emissions; green construction/buildings; renewable energy projects; solar projects; and wind projects.

Finally, we determine a dollar measure of the yield advantage from issuing green bonds, which in the literature often is referred to as greenium. We start by collecting the green bond's issue yield, as well as the same-day yield of a matched non-green bond of the same issuer. To determine the matched non-green bond, we consider bonds of the same type (fixed, floating) and currency. Out of these bonds, we select the one closest with respect to the following criteria: the natural log of the issue amount, maturity, coupon, and number of days between the green and non-green bond issue dates. Closeness is measured using the Mahalanobis distance.

Next, we determine the dollar advantage (or disadvantage) from issuing a green bond. It depends on bond characteristics as well as the issue amount. With $P(I, M, c, y)$ denoting the percentage price of a bond with a settlement equal to the issue date I, maturity date M, coupon rate c, and yield to maturity y, we determine the dollar benefit $DollarGreenium$ from a single bond issue as follows:

$$DollarGreenium = (P(I, M, c, y_{Green}) - P(I, M, c, y_{Matched\ nongreen})) \cdot USDIssueAmount \tag{1}$$

Finally, we cumulate the $DollarGreenium$ of each green bond that firm i issued until year t, scale the sum by the firm's revenue in t, and multiply the ratio by 1,000 to facilitate presentation. The resulting variable, $GreeniumEffect_{i,t}$, captures the cumulative pricing advantage (when positive, or else a disadvantage) that the issuance of green bonds brought relative to the issuance of brown bonds.

Similar to the issue volume, we also define dummy variables that indicate relatively high greenium effects. $HighGreeniumEffect_{i,t}$ takes the value one if the value of $GreeniumEffect_{i,t}$ is above the median $GreeniumEffect_{t}$ of firms that have outstanding green bonds in t.

The precision of the greenium effect variable is reduced by the fact that the effects cannot be determined for each green bond issue. If a firm issued no non-green bonds, or if the required yield information is not available in Refinitiv, we cannot determine the *DollarGreenium.* Nevertheless, we compute and use $GreeniumEffect_{i,t}$.[8]

Finally, all variables defined as a ratio are winsorized at the 2.5% and 97.5% levels by year. Winsorization by year appears to be adequate because the regression variables exhibit time

[8] To control for possible biases from missing information, we also ran regressions that include dummy variables that take the value one if a firm has issued a green bond for which *DollarGreenium* could not be determined. Conclusions do not change.

patterns. For example, the green bond issue volume $OutVolume$ is equal to zero in 2010 for all firms, then tends to increase over time.[9]

The variable definitions and data sources are summarized in the Appendix.

Regression approach

As in Flammer (2021), we run fixed-effect regressions of the following form:

$$CarbonIntensity_{i,t} = \alpha_i + \alpha_{c(i)} \times \alpha_t + \alpha_{s(i)} \times \alpha_t + \beta' x_{i,t} + u_{it} \qquad (2)$$

in which $x_{i,t}$ is a vector of variables related to green bond issues of firm i. The country in which firm i is domiciled is denoted as $c(i)$, and the two-digit standard industrial classification (SIC) industry in which it operates is denoted as $s(i)$. The regression includes firm fixed effects α_i, country-year fixed effects $\alpha_{c(i)} \times \alpha_t$, and industry-year fixed effects $\alpha_{s(i)} \times \alpha_t$. We estimate standard errors that are robust to clustering on the two-digit SIC level.

In the base case specification of (2), we follow Flammer (2021) and apply a matched control firm approach. For each firm that has issued a green bond, we determine a nearest neighbor out of the firms that did not issue a green bond until the end of our sample. To qualify as a neighbor, firms must be domiciled in the same country as the green bond issuer and operate in the same two-digit industry. Characteristics used in the matching process are from the year before the first green bond issue. In the first round of matching, we use the Mahalanobis distance to find the nearest neighbor according to seven characteristics—$Leverage$, $Size$, ROA, $TobinQ$, and the ASSET4 environmental, social, and governance scores—as well as the one-year changes in these characteristics, ending in the year before the green bond issue. Therefore, the total number of matching variables is 14. In a second round, to increase the number of matches, we determine neighbors for firms that remained without a neighbor after the first round, using only the four characteristics $Leverage$, $Size$, ROA, $TobinQ$ as well as their one-year changes.

The sample of firms used for regression (2) comprises all green bond issuers for which a neighbor was found, as well as all non-green bond issuers that have been selected as a nearest neighbor. We follow Flammer in (i) running the regression with firm years from 2010 to the end of the sample in 2020, and in (ii) not including firm-level control variables. The motivation

[9] Note that in the regressions, average time patterns are captured by time-fixed effects.

for the latter is that candidates for control variables, such as leverage, have been taken into account in the matching process. Robustness to this modeling choice will be checked.

Regarding the green bond variables contained in the vector x, the previous section has already introduced the variables we will consider. In the results section, we will discuss the appropriate choice of lags for the variables in x. Finally, note that we will also check the sensitivity of results to the regression specifications. For example, we will also report results obtained if regression (2) is run using data from all companies contained in the ASSET4 universe.

3. Empirical results

Descriptive statistics

Table 1 provides year-by-year information on the number of green bond issues, issuers, and issue amounts. Numbers are for publicly listed non-financial issuers with CO2 emission data and thus provide information on the green bond issues that find their way into the explanatory variables of the subsequent regression analysis. Table 2 provides the corresponding information by the country in which the issuer is domiciled.

When comparing the figures reported here to other studies' descriptive statistics, it is important to take into account that Table 1 and Table 2 provide information for the subset of green bond issuers that fulfill the requirements of the subsequent regression analysis.

For example, to compare our dataset's size to that of Flammer (2021), note that her regression analysis of carbon intensity is built on 132 issuers for which CO2 emission data are available and that have been matched to a non-green issuer.[10] This number is smaller than the 159 issuers we report in Table 2, even though our dataset is restricted to non-financial firms, while the 132 issuers in Flammer (2021) include financial firms.

For 157 issues, we can determine the difference between the issue yield and the yield of a matched non-green bond from the same issuer. The difference, or greenium, averages −0.071%, with a standard error of 0.079%. The small average greenium is consistent with previous studies (e.g., Zerbib, 2019; Flammer, 2021). The magnitude of the missing data problem is similar to that of other studies as well. We can determine the greenium for 43% of the green bond issues; Flammer (2021) can compute the greenium for 27% of the green bond issues she considers.[11]

[10] Cf. Flammer (2021), Table 9.

[11] Table 13 in Flammer (2021) reports the greenium for 152 issues out of 565 issues mentioned on p. 513 of Flammer (2021).

To assess whether issuing green bonds has the potential to strengthen a firm's ability to reduce carbon emissions materially, we next relate issue amounts and dollar benefits from yield advantages to a firm's carbon emissions. Specifically, we relate the total USD issue amount in year t to the issuer's CO2 emissions in t, and we relate the sum of $DollarGreenium$ in year t to the issuer's CO2 emissions in t.

Table 3 reports quantiles of these ratios, computed over firm years during which a green bond was issued. The median total issue amount per ton of CO2 is USD 399.6. This seems large enough to enable firms to lower their carbon footprint significantly. For several power-generating technologies, Gillingham and Stock (2018) present estimates of the cost per ton of CO2 saved relative to a coal-fired power plant. The maximum of their cost estimates is USD 132 per ton of CO2, smaller than the median issue amount per year. This does not mean that it would be possible for the median issuer to use the green bond proceeds to bring its CO2 emissions immediately down to zero. First, a delay exists between investments and CO2 savings, not only because it takes some time to implement investment projects, but also because cost estimates such as the ones reported in Gillingham and Stock (2018) are computed over a project's lifetime. Second, in some production processes, the cost of replacing fossil energy sources could be considerably higher than the cost of reducing CO2 emissions in power generation for which estimates are available.

Nevertheless, the observation that the issue volume per year often exceeds the money needed to finance investments with lifetime CO2 savings equal to current CO2 emissions indicates that green bond issue volumes are not too small to have a direct effect on a firm's carbon footprint. Consider the following back-of-the-envelope calculation: At the 75% quantile, the issue volume per ton of CO2 (USD 4,668) is more than 35 times higher than the highest estimate of the cost per ton of CO2 abated (USD 132) from Gillingham and Stock (2018). If a firm with an issue volume at the 75% quantile invests in such projects, and these projects have a lifetime of 35 years or less, with evenly distributed CO2 savings, the issue volume would be sufficient to save as much CO2 as the firm currently emits; not just once, but each year over the projects' lifetime.

Note that Flammer (2021, p. 501) arrives at a different assessment of whether green bond financing is large enough to make an environmental impact: "The green bonds themselves are likely too small to bring about significant improvements at the firm level." To support the view that green bond volumes are too small to matter, Flammer (2021) compares the average green bond issue amount to average total assets. Considering that many firms issue several green bonds in a year, the issue amount per year that we use seems to be a more informative measure of green bond size than the size of individual issues. Also, relating issue volumes to carbon emissions rather than to total assets seems to provide more information on the enabling potential of green bond financing.

When we limit our analysis to climate-related issues, the quantiles provided in Table 3 do not change in a way that would affect our conclusion that volumes are large enough to have an effect. The situation is different for the benefit that firms get from being able to issue bonds at favorable prices. Not only is the median total dollar benefit negative. The 75% quantile is USD 1.8 per ton of CO2 emitted, which appears to be too low to have a sizable impact on the firm's ability to lower its carbon emissions. Examining more extreme quantiles does not change conclusions: The 90% quantile is USD 14.33 per ton of CO2.

Figure 1 plots average carbon intensity across time, separately for firms that issued at least one green bond during the 2010–2020 period, and the set of matched control firms. Panel A provides the equal-weighted average of carbon intensities, while Panel B provides the revenue-weighted average. The latter is equivalent to the ratio of total carbon emissions in a group divided by total revenue in that group; it is more informative for judging environmental consequences than the equal-weighted average. Panel B shows that the overall carbon intensity of green bond issuers has been trending downward, unlike the trend exhibited by matched firms that did not issue green bonds. This is not enough to indicate that green bond issuance is associated with lower carbon intensity, particularly because green bond issuance gradually set in over time. However, it already suggests that green bond investors concerned about the carbon reduction paths of the firms in their portfolios did not back the wrong horses.

The regression analysis in the next section will shed more light on the association between green bond issuance and carbon intensity. Descriptive statistics for the regression variables and the variables used for matching a non-green firm to each green bond issuer are provided in Table 4. We show statistics for the second lag of explanatory variables because the variables will enter the main regression specification with such a lag.

The means of variables related to green bonds may appear low. This can be explained as follows: First, they take the value of zero for all matched brown firms, which comprise roughly 50% of the observations.[12] Second, up until the year after the first green bond issue, the second lags of the green bond variables take the value of zero for green bond issuers as well.

[12] Observations for matched firms do not comprise exactly 50% of the observations for two reasons: (i) A firm can be matched to more than one green bond issuer; and (ii) because of delistings, observations available for a green bond issuer need not be the same as the observations available for the matched firm.

Comparing the figures for all firms with the ones for green bond issuers reported in Panel B does not reveal striking differences between green bond issuers and matched firms. Note that the number of observations for matching variables, such as $Leverage$, is smaller than for the regression variables because the table provides information for the subset for which the regression variables are non-missing, not for the smaller subset for which both regression variables and variables used in the matching process are non-missing.

Regression results

We start by regressing carbon intensity on the green bond issue dummies, following and extending the analysis in Flammer (2021). The results are provided in Table 5. As regression (1) indicates, firms that have issued a green bond by year t, i.e., firms for which the variable $GreenBond_t$ is one, are predicted to have a lower carbon intensity, significant at a level of 5%.

Regression (2) examines the dynamics of this relationship. We split $GreenBond_{i,t}$ into two short-term dummies that indicate whether the first green bond was issued in the current or previous year, and the two-year lag of $GreenBond$.[13] The insignificance of the short-term dummies $FirstGreenBond_{i,t}$ and $FirstGreenBond_{i,t-1}$ suggest that it takes around two years until green bond issuance becomes informative for carbon intensity. Lagging the $GreenBond$ dummy by two years leads to a larger coefficient (in absolute terms) and a higher significance level.

In regressions (3) and (4), the short-term dummies gradually are eliminated without affecting the estimate of $GreenBond_{t-2}$ in a substantial way. The magnitude of the coefficient of $GreenBond_{t-2}$ appears to be economically significant. Based on the estimate from regression (4), a firm that has issued the first green bonds two years ago or earlier emits 197.73 tons of CO2 less per USD million of revenue. For a firm with a carbon intensity equal to the average of 747.5, this amounts to a reduction of 26%.

In the final regression of Table 5, we examine how estimates change if we consider only climate-related green bond issues. Results do not change materially. The coefficient of $ClimateGreenBond_{i,t-2}$ is -209.5, with a standard error of 77.9, close to the coefficient of -197.7 obtained for $GreenBond_{i,t-2}$ in regression (4).

[13] From the definition of the variables, $GreenBond_{i,t}$ is equal to the sum of $FirstGreenBond_{i,t}$, $FirstGreenBond_{i,t-1}$, and $GreenBond_{i,t-2}$.

Overall, results from Table 5 are consistent with the interpretation of green bonds as a signaling device, put forth in Flammer (2021), as well as with similar explanations in which the issuance of green bonds serves as an indicator or catalyst for environmental improvements. The analysis of lag structures suggests that the relationship is not immediate and becomes visible two years after the green bond issuance. This appears reasonable given that many strategies for reducing CO2 emissions—such as investments in renewable energy sources, energy efficiency, or research and development—take some time to bear fruit.

In the following, we will examine whether differences in the financial advantages that firms derive from green bonds matter in addition to the information contained in the decision to issue green bonds. To capture the latter, the results from Table 5 suggest that it is sufficient to include the lagged green bond dummy $GreenBond_{i,t-2}$. Again in line with the evidence from Table 5, we will lag the variables that measure financial benefits from green bond issuance by two years.

In regression (1) of Table 6, we add the second lag of the volume of outstanding green bonds ($OutVolume$), as well as the second lag of cumulated pricing-related benefits associated with green bonds (*GreeniumEffect*). The coefficient of $OutVolume_{i,t-2}$ is –2.33, significant at the 1% level. Therefore, higher cumulated green bond issue volume is associated with lower future carbon intensity. Among the firms that issue green bonds, a two-standard-deviation increase in $OutVolume_{i,t-2}$ would imply a predicted change in carbon intensity equal to $-2.33 \times 2 \times 23.39 = -109.00$. This is larger in absolute value than the coefficient of $GreenBond_{i,t-2}$, meaning that differences in issue volume can bear a relevance larger than the differences between green bond issuers and firms that have not (yet) issued green bonds.

The coefficient of $\textit{GreeniumEffect}_{i,t-2}$, which captures pricing advantages (or disadvantages) of green bond issues, is also negative, but it is not significant.

Signs and significance do not change when we replace the continuous variables with dummy variables that indicate whether the volume outstanding or the pricing advantage of green bond issues is above the cross-sectional median. With this dummy variable specification, it is also easier to interpret the magnitude of the coefficient estimates. In absolute terms, the coefficient of $HighOutVolume_{i,t-2}$ is larger than the coefficient of $GreenBond_{i,t-2}$, indicating that green bond issuance as such is less informative for future carbon intensity than the relative amounts of bonds issued. For a green bond issuer with a mean carbon intensity, belonging to the group with high outstanding volumes would be predicted to reduce carbon intensity by $-166.17/787.40 = -21.1\%$.

Regressions (3) and (4) consider only climate-related green bonds for the construction of the issue-related variables. In absolute terms, the coefficients are larger than the corresponding coefficients in regressions (1) and (2). This is what one would expect if issue proceeds are used according to the information that the firm provides at issuance. The final regression shows that this pattern does not change if the dummy variable for green bond issuance is also constructed with climate-related green bonds only.

In short, the analysis does not elicit reliable evidence that pricing advantages from green bond issuance are informative for future reductions in carbon intensity, but it does so for the outstanding volume of green bonds. The regressions cannot establish that the documented relationships are causal. A possible alternative explanation is that firms that already initiated a reduction in carbon emissions issue large amounts of climate-related bonds because they expect it to be easy to fulfill promises made to green bond investors.

As discussed in the descriptive statistics section, however, the green bond issue volumes appear to be large enough to finance significant reductions in carbon intensity. Thus, the potential for direct effects appears to be present.

To shed additional light on the question of whether or not green bonds make a difference in emissions, we examine cross-sectional differences in the association between green bond issuance and carbon reductions. If green bonds provide opportunities beyond traditional financing sources, firms for whom traditional financing is costly or difficult to get could derive relatively large benefits from green bond issuance. To test this hypothesis, we use the KZ index of Lamont, Polk, and Saa-Requejo (2001) to sort firms according to the extent of financial constraints, and the Z-score of Altman (1968) to sort firms according to credit risk. A lower Z-score indicates a higher credit risk; a higher KZ index indicates higher financial constraints.

Specifically, we augment regressions (1) and (2) from Table 6 by interacting the issue volume and greenium variables with indicator variables that take the value one if: (i) a firm's KZ index is above the cross-sectional median, or (ii) a firm's Z-score is below the cross-sectional median. Furthermore, we also include dummy variables for firms with a KZ index above the median, or firms with a Z-score below the median.

The results are presented in

Table 7. Based on how the new variables are constructed, negative coefficients of the interaction terms imply a stronger association between the interacted green bond variable and future carbon reductions.

For the outstanding volume of green bonds, the interaction terms are all negative. Only two of them are significant at levels of 10% or better. However, it is not sufficient to look at the significance of the interaction terms. The total effect for firms with financing difficulties is given by the sum of the coefficients of the volume variable and the interacted variable. P-values for the null that this sum is zero are reported at the bottom of the table. They are all below 5%, both for the grouping according to the KZ index, as well as for the grouping according to the Z-score. Therefore, the evidence is consistent with funds from green bond issues that enable risky and financially constrained firms to reduce their carbon emissions. On the other hand, because the coefficients of non-interacted volume variables are no longer significantly negative, there is no significant evidence that green bond volumes precede lower carbon emissions if issuers have below-average credit risk or financial constraints. To put it differently, investors who care about making a measurable impact on the environment possibly would have made a greater impact by investing their money in other projects, instead of buying green bonds issued by firms with low credit risk and few financial constraints.

The variables that interact the pricing advantage from bond issuance with indicators of high credit risk or high financial constraints are positive. None of the interaction terms is significant, nor is the total effect for firms with high financial constraints or high credit risk significantly different from zero.

Sensitivity analysis

To check how sensitive the results are to changes in definitions of variables and specifications of the regression, we examine the following non-accumulating variations of Table 6:

(1) We winsorize all ratios at the 1% and 99% levels, rather than at the 2.5% and 97.5% levels.

(2) We lag the variables capturing the volume and pricing advantage of green bond issues by one year, rather than two years.

(3) Instead of using a matched control firm approach, we run the regressions with all non-financial firms included in the ASSET4 universe.[14]

[14] For this variation, we changed the winsorization levels for the explanatory variables from 2.5% and 97.5%, to 0.25% and 99.75%, because the number of observations goes up by a factor of roughly 10, with all additional observations having zero values for the green bond variables. If we did not make the winsorization levels more extreme, non-zero values of green bond issuers mostly would be pulled to zero.

(4) Instead of using both reported and estimated figures for carbon emissions, we limit the analysis to observations for which reported carbon emissions data are available.

(5) We scale carbon emissions and volume and greenium data by total assets, rather than revenue.

(6) We use the Refinitiv environmental score as dependent variable, rather than carbon intensity.

Results for regressions that vary specification (1) from Table 6 are presented in Table 8. In variations (1) to (5), which retain carbon intensity as dependent variable, the coefficient of outstanding green bond volume is always negative and significant at the 5% level, confirming the previous conclusions. When carbon intensity is replaced by Refinitiv's environmental score, the sign switches to positive. This is consistent with the results from the carbon intensity regressions because a higher score indicates a better environmental performance. In an unreported additional analysis, we also confirm that conclusions do not change when the firm controls $Leverage_{i,t\text{-}2}$, $Size_{i,t\text{-}2}$, $ROA_{i,t\text{-}2}$, and $TOBINQ_{i,t\text{-}2}$ are added to the set of explanatory variables.[15]

Coefficient estimates of the variables capturing the greenium advantage are also consistently such that higher pricing advantages are associated with lower carbon intensity or better environmental performance. Different to the base case regressions from Table 6, however, several coefficients are now significant at the 5% or 10% level. Therefore, the conclusions of the previous section need to be supplemented by saying that some evidence indicates an association between pricing advantages from green bond issues and lower future carbon intensity. This again elicits the question of whether such an association could be due to a direct effect. For the variations presented in Table 8, we augment the variables with interaction terms that capture differences in credit risk and financial constraints, as in

Table 7. Unreported results reveal that none of the interaction terms of the greenium variable has a significantly negative sign; therefore, no indirect support exists for a direct greenium effect. Also, Table 3 indicates that the magnitude of the pricing advantage is fairly small relative to carbon emissions. The 75% quantile of the advantage is USD 1.8 per ton of carbon emitted, making it implausible that the pricing advantage helps firms lower carbon emissions. An alternative explanation for the association that is documented in most regressions from Table 8 is that the market is able to predict differences in carbon emission paths. If there are investors

[15] Coefficients (standard errors) are -1.99 (0.53) for $OutVolume_{i,t\text{-}2}$ and -362.76 (404.50) for $GreeniumEffect_{i,t\text{-}2}$.

with a preference for investing in firms with high future carbon reductions, they could drive up demand for green bonds issued by such firms, which could result in lower yields of these bonds.

4. Concluding remarks

Green bond investors are promised a measurable environmental impact from their investments. Whether green bonds actually have such an impact has not been addressed fully in extant literature. Flammer (2021) and Fatica and Panzica (2021) show that green bond issue activity makes a difference, but they do not address the question of whether incremental issue volumes or pricing advantages from green bond issuance make a difference for the environment.

In the present paper, we document that higher green bond issue volumes predict future carbon reductions of non-financial corporates. Establishing causality lies beyond the scope of this paper, but two observations are consistent with direct effects being at work. First, issue volumes relative to carbon emissions can be so large that financing carbon-reduction projects with green bond proceeds would make a meaningful impact on a firm's carbon emissions. Second, the association between green bond issue volume and carbon reductions is stronger for firms with a higher credit risk or higher financial constraints. It is plausible that for these firms, the alternative financing option that green bonds offer can be particularly helpful.

On the other hand, there is no significant relationship between green bond issue volumes and carbon reductions for firms with a low credit risk and low financial constraints. Therefore, it is not evident that providing incremental green bond financing to such firms makes a difference for the environment. Investors concerned about the impact of their investments could benefit from screening issuers according to financial needs, or from considering alternative ways of achieving an impact. Innovative security designs, such as sustainability-linked bonds or green certificates (Bongaerts and Schoenmaker, 2020), possibly can help facilitate the allocational role of green financing and transparency with respect to impact.

Consistent with previous studies (e.g., Zerbib, 2019), green bonds in our sample exhibit a small pricing advantage compared with non-green bonds. However, we find some evidence that variation in pricing advantages predicts variation in future carbon reductions. Unlike with issue volumes, there is no indirect support for direct effects. Even for firms that enjoy a large pricing advantage, the size of the advantage is very small relative to carbon emissions. Furthermore, the predictive relationship is not stronger for firms with a high credit risk or high financial constraints. A possible alternative explanation is that market participants are able to predict carbon-reduction paths, and that green bond investors bid up prices of bonds issued by firms with high predicted carbon reductions.

Appendix: Variable definitions

Variable name	Description	Data source and computation details (Capital letters indicate Datastream datatypes)
Regression variables		
$CarbonIntensity_{i,t}$	CO2 equivalents in tons/revenue in USD millions	ENERDP123/WC07240
$Greenbond_{i,t}$	Takes the value one if a firm has issued a green bond by year t, and zero otherwise	Finance Bond Database, Climate Bond Initiative, and the Refinitiv Green Bond Guide
$FirstGreenBond_{i,t}$	Takes the value one if a firm issued its first green bond in year t.	Finance Bond Database, Climate Bond Initiative, and the Refinitiv Green Bond Guide
$ClimateGreenbond_{i,t}$	Takes the value of one if a firm has issued a climate-related green bond by year t.	Finance Bond Database and the Refinitiv Green Bond Guide
$OutVolume_{i,t}$	Volume of green bonds outstanding at the end of year t divided by revenue in year t.	(Cumulated AISD)/WC07240×10^3
$ClimateOutVolume_{i,t}$	Volume of climate-related green bonds outstanding at the end of year t divided by revenue in year t.	(Cumulated climate-related AISD)/WC07240×10^3
$GreeniumEffect_{i,t}$	Cumulative sum of the $DollarGreenium$ values of a firm's green bonds until t, divided by revenue in year t.	Finance Bond Database, Climate Bond Initiative, and the Refinitiv Green Bond Guide, Eikon, Datastream
$High[Variable]_{i,t}$	Dummy variable equal to one if $[Variable_{i,t}]$ is above the cross-sectional median of $[Variable_t]$ of firms that have green bonds outstanding in t.	See information for base variable.
Variables used in the definition of other variables		
$DollarGreenium$	Market value of a green bond at issue minus hypothetical market value of a bond with the same principal, maturity and coupon but yield of matched non-green bond of the same issuer	Finance Bond Database, Climate Bond Initiative, and the Refinitiv Green Bond Guide, Eikon, Datastream
Variables used for finding matched firms with no green bond issue		
$Leverage_{i,t}$	Total debt/total assets	WC03255/WC02999
$Size_{i,t}$	Ln (total assets in USD)	ln(WC07230)
$ROA_{i,t}$	Return on assets (in %)	WC08326
$TOBINQ_{i,t}$	Tobin's Q	(WC02999+WC08002–WC03501)/WC02999
$EnvironScore_{i,t}$	Refinitiv environmental score	ENSCORE
Variables used for cross-sectional hypotheses		
Z-Score	Credit risk score of Altman (1968)	Variables used: WC03151 (working capital); WC02999 (total assets); WC03351(retained earnings); WC18191 (EBIT); WC08002 (market cap); WC03351 (total

		liabilities); and WCO1001 (revenue)
KZ index	Index of financial constraints based on Lamont, Polk, and Saa-Requejo (2001)	Variables used: WC01651 (income before extraordinary items); WC01151 (depreciation); WC02501 (property, plant, and equipment); variables as for $TobinQ$; WC03255+WC03501 (total capital); WC02001 (cash); and WC05376 (dividends)

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Table 1: Green bond issues of publicly listed non-financial corporates with carbon emission data—by year of issuance

Green bond information is taken from the Environmental Finance Bond Database (EFBD), Climate Bond Initiative (CBI), and Refinitiv Green Bond Guide. The table provides statistics on non-financial corporates that are publicly listed and for which carbon emission data are available at some point during the sample period. We classify a bond issue as climate-related if its proceeds are used for energy efficiency, renewable energy, or other purposes relevant for climate change mitigation. A total for the number of bond issuers is not provided because one issuer can contribute to issuer counts in multiple years.

	No. of green bond issues		No. of green bond issuers		Issue amount (billions of $)	
Year	All	of which climate-related	All	with climate-related issues	All	of which climate-related
2012	1	0	1	0	0.65	0.00
2013	2	2	2	2	1.91	1.91
2014	15	14	10	9	8.30	7.62
2015	14	13	9	9	7.24	6.67
2016	14	12	10	9	9.39	8.95
2017	48	33	28	23	21.13	15.23
2018	46	27	35	23	15.67	13.44
2019	108	66	68	48	47.31	33.84
2020	108	58	61	40	50.71	29.01
Total	356	225			162.30	116.67

Table 2: Green bond issues of publicly listed non-financial corporates with carbon emission data—by country

Green bond information is taken from the Environmental Finance Bond Database (EFBD), Climate Bond Initiative (CBI), and the Refinitiv Green Bond Guide. The table provides statistics on non-financial corporates that are publicly listed and for which carbon emission data are available at some point during the sample period. We classify a bond issue as climate-related if its proceeds are used for energy efficiency, renewable energy, or other purposes relevant for climate change mitigation.

	No. of green bond issues		No. of green bond issuers		Issue amount (billions of $)	
Issuer domicile	All	climate-related	All	with climate-related issues	All	climate-related
Argentina	2	0	1	0	1.00	0.00
Australia	1	1	1	1	0.28	0.28
Austria	1	1	1	1	0.63	0.63
Brazil	11	7	6	6	4.29	2.53
Canada	2	2	2	2	0.40	0.40
Chile	3	1	2	1	0.45	0.45
China	12	9	6	4	2.69	2.36
Denmark	4	4	2	2	2.66	2.66
Finland	5	2	2	2	2.14	1.50
France	30	17	12	7	25.57	16.53
Germany	20	11	11	9	13.54	7.91
Greece	4	3	2	1	1.32	1.16
Hong Kong	28	12	9	9	6.48	3.60
India	5	5	2	2	2.02	2.02
Italy	21	18	8	8	13.99	12.07
Japan	26	12	20	10	3.49	1.14
Mexico	1	0	1	0	0.71	0.00
Netherlands	4	2	2	1	2.27	1.10
New Zealand	6	4	2	1	0.54	0.36
Norway	3	1	3	1	0.50	0.22
Philippines	1	0	1	0	0.50	0.00
Portugal	7	6	1	1	5.84	4.99
Singapore	6	2	1	1	0.84	0.26
South Korea	12	5	4	3	5.99	2.35
Spain	41	32	7	7	18.55	17.79
Sweden	20	8	10	6	2.82	1.52
Switzerland	3	2	3	2	2.93	0.74
Taiwan	6	5	4	3	0.89	0.82
UK	9	6	5	4	3.90	3.32
United States	62	47	28	22	35.07	27.94
Total	356	225	159	117	162.30	116.67

Table 3: Annual benefits from green bond issues per ton of issuer CO2 emissions

The total issue amount in year *t* is the sum of green bond issue amounts in USD in year *t*. For the total climate-related issue amount, only climate-related green bonds are considered. The total dollar benefit from yield advantages is the annual sum of USD pricing advantages from green bond issues. Statistics are reported only for firm years in which there was a green bond issue. Missing values for the yield advantage are not set to zero and therefore lower the number of observations relative to the ones available for the yearly issue amounts.

	N	Median	25% Quantile	75% Quantile
Total issue amount in *t* / CO2 emissions in *t*	280	399.6	77.3	4,668.0
Total climate-related issue amount in *t* / CO2 emissions in *t*	202	374.8	60.4	3,839.0
Total dollar benefit from yield advantage in *t* / CO2 emissions in *t*	139	−0.3	−21.8	1.8

Table 4: Summary statistics for regression variables

$CarbonIntensity$ is defined as CO2 emissions in tons scaled by revenue in USD millions. The dummy variable $Greenbond_{i,t}$ takes the value one if firm i has issued a green bond by year t. $OutVolume_{i,t}$ is the volume of a firm's green bonds outstanding at the end of year t, scaled by revenue. With the prefix *Climate*, the variable is defined for the subset of climate-related bonds. $GreeniumEffect_{i,t}$ is the cumulative pricing advantage (when positive, or else a disadvantage) that the issuance of green bonds has brought relative to the issuance of brown bonds by year t. The sample covers the years 2010–2020 and includes firms with green bond issues, as well as matched control firms.

	N	Mean	Median	Std. Dev.	Min	Max
Panel A: Both green bond issuers and matched control firms						
$CarbonIntensity_{i,t}$	3,309	747.500	78.01	1,626.00	0.00	8,959.00
$Greenbond_{i,t-2}$	3,309	0.038	0.00	0.19	0.00	1.00
$OutVolume_{i,t-2}$	3,309	2.037	0.00	15.33	0.00	241.10
$ClimateOutVolume_{i,t-2}$	3,309	1.284	0.00	9.63	0.00	141.50
$GreeniumEffect_{i,t-2}$	3,309	−0.001	0.00	0.03	−0.65	0.43
$Leverage_{i,t-2}$	3,300	0.325	0.32	0.16	0.00	0.84
$Size_{i,t-2}$	3,300	16.430	16.41	1.31	12.07	20.06
$ROA_{i,t-2}$	3,292	5.215	4.47	5.96	−50.32	128.40
$TOBINQ_{i,t-2}$	3,264	1.391	1.18	0.70	0.27	8.79
$EnvironScore_{i,t-2}$	3,013	57.200	63.29	26.79	0.00	98.17
Panel B: Green bond issuers only						
$CarbonIntensity_{i,t}$	1,388	787.400	103.50	1,630.00	0.00	8,959.00
$Greenbond_{i,t-2}$	1,388	0.091	0.00	0.29	0.00	1.00
$OutVolume_{i,t-2}$	1,388	4.857	0.00	23.39	0.00	241.10
$ClimateOutVolume_{i,t-2}$	1,388	3.061	0.00	14.68	0.00	141.50
$GreeniumEffect_{i,t-2}$	1,388	−0.002	0.00	0.05	−0.65	0.43
$Leverage_{i,t-2}$	1,386	0.334	0.33	0.14	0.00	0.83
$Size_{i,t-2}$	1,386	16.840	16.77	1.29	12.81	20.06
$ROA_{i,t-2}$	1,383	5.262	4.45	5.92	−15.13	128.40
$TOBINQ_{i,t-2}$	1,378	1.396	1.18	0.66	0.27	7.91
$EnvironScore_{i,t-2}$	1,299	64.590	70.92	23.93	0.00	97.47

Table 5: Green bond issuance and carbon intensity

$CarbonIntensity$ is defined as CO2 emissions in tons scaled by revenue in USD millions. The dummy variable $Greenbond_{i,t}$ takes the value one if firm i has issued a green bond by year t. $FirstGreenbond_{i,t}$ equals one if the first green bond issue occurred in year t. The sample covers the years 2010–2020 and includes firms with green bond issues, as well as matched control firms. Standard errors (in parentheses) of the regression coefficients are estimated using clustering on two-digit SIC levels. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Dependent Variable: $CarbonIntensity_{it}$				
	(1)	(2)	(3)	(4)	(5)
$Greenbond_{i,t}$	−57.38**				
	(21.39)				
$FirstGreenbond_{i,t}$		16.89			
		(60.67)			
$FirstGreenbond_{i,t-1}$		−76.20	−80.93		
		(94.96)	(107.70)		
$Greenbond_{i,t-2}$		−213.85***	−219.40**	−197.73***	
		(71.73)	(86.73)	(71.57)	
$ClimateGreenbond_{i,t-2}$					−209.49**
					(77.91)
Company FE	YES	YES	YES	YES	YES
CountryYear FE	YES	YES	YES	YES	YES
IndustryYear FE	YES	YES	YES	YES	YES
Observations	3,309	3,309	3,309	3,309	3,309
R-squared	0.94	0.94	0.94	0.94	0.94

Table 6: Financial benefits from green bond issuance and future carbon intensity

$CarbonIntensity$ is defined as CO2 emissions in tons scaled by revenue in USD millions. The dummy variable $Greenbond_{i,t}$ takes the value one if firm i has issued a green bond by year t. $OutVolume_{i,t}$ is the volume of a firm's green bonds outstanding at the end of year t, scaled by revenue. With the prefix *Climate*, the variable is defined for the subset of climate-related bonds. $GreeniumEffect_{i,t}$ is the cumulative pricing advantage (when positive, or else a disadvantage) that the issuance of green bonds has elicited relative to the issuance of brown bonds by year t. The prefix *High* indicates dummy variables that are equal to one if the variable without a prefix is above the cross-sectional median of firms with green bonds outstanding. The sample covers the years 2010–2020 and includes firms with green bond issues, as well as matched control firms. Standard errors (in parentheses) of the regression coefficients are estimated using clustering on two-digit SIC levels. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Dependent variable: $CarbonIntensity_{it}$				
	(1)	(2)	(3)	(4)	(5)
$Greenbond_{i,t-2}$	−86.79**	−96.38	−77.96	−104.74*	
	(40.35)	(58.91)	(59.64)	(55.99)	
$ClimGreenbond_{i,t-2}$					−101.93
					(62.51)
$OutVolume_{i,t-2}$	−2.33***				
	(0.63)				
$HighOutVolume_{i,t-2}$		−166.17***			
		(57.26)			
$ClimateOutVolume_{i,t-2}$			−3.82***		
			(1.03)		
$HighClimateOutVolume_{i,t-2}$				−179.30***	−176.72***
				(51.74)	(38.83)
$GreeniumEffect_{i,t-2}$	−254.11		−131.33		
	(277.60)		(276.68)		
$HighGreeniumEffect_{i,t-2}$		−229.22		−229.10	−242.65
		(198.70)		(197.02)	(218.51)
Company FE	YES	YES	YES	YES	YES
CountryYear FE	YES	YES	YES	YES	YES
IndustryYear FE	YES	YES	YES	YES	YES
Observations	3,309	3,309	3,309	3,309	3,309
R-squared	0.94	0.94	0.94	0.94	0.94

Table 7: Cross-sectional differences in the relationship between financial benefits from green bond issuance and future carbon intensity

The table presents variations of regressions (1) and (2) from Table 6. The variables capturing the benefits from green bond issuance are interacted with a dummy variable *Indicator* that is meant to capture differences in the extent to which firms benefit from financing advantages. We define *Indicator* in two different ways: (i) It takes the value of one if the KZ index of Lamont, Polk, and Saa-Requejo (2001) is above its cross-sectional median; or (ii) it takes the value of one if the Z-score of Altman (1968) is below its cross-sectional median. Standard errors (in parentheses) of the regression coefficients are estimated using clustering on two-digit SIC levels. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Indicator = KZ index is above its cross-sectional median		*Indicator* = Z-score is below its cross-sectional median	
	(1)	(2)	(3)	(4)
$Greenbond_{i,t-2}$	−125.96***	−91.61	−101.92**	−83.62
	(39.75)	(54.66)	(44.51)	(54.84)
$OutVolume_{i,t-2}$	0.99		−1.99	
	(0.86)		(1.19)	
$OutVolume_{i,t-2}$	−3.32*		−0.18	
× $Indicator_{i,t-2}$	(1.70)		(0.69)	
$GreeniumEffect_{i,t-2}$	−2,265.51		−1,185.27	
	(1,521.53)		(966.12)	
$GreeniumEffect_{i,t-2}$	2,239.82		1,212.52	
× $Indicator_{i,t-2}$	(1,515.35)		(985.12)	
$HighOutVolume_{i,t-1}$		172.72**		−185.04
		(74.22)		(203.98)
$HighOutVolume_{i,t-1}$		−437.73***		−17.76
× $Indicator_{i,t-2}$		(116.66)		(250.46)
$HighGreeniumEffect_{i,t-2}$		−660.91		−694.57
		(630.87)		(483.70)
$HighGreeniumEffect_{i,t-2}$		627.08		642.37
× $Indicator_{i,t-2}$		(648.91)		(494.63)
$Indicator_{i,t-2}$	69.25*	69.87	69.40	65.03
	(40.73)	(41.77)	(64.23)	(60.86)
Company FE	YES	YES	YES	YES
CountryYear FE	YES	YES	YES	YES
IndustryYear FE	YES	YES	YES	YES
p (H_0: volume variable + interacted volume variable = 0)	0.040	0.000	0.009	0.002
p (H_0: greenium variable + interacted greenium variable = 0)	0.745	0.716	0.761	0.136
Observations	3,309	3,309	3,309	3,309
R-squared	0.94	0.94	0.94	0.94

Table 8: Variations of regressions examining the relationship between financial benefits from green bond issuance and future environmental performance

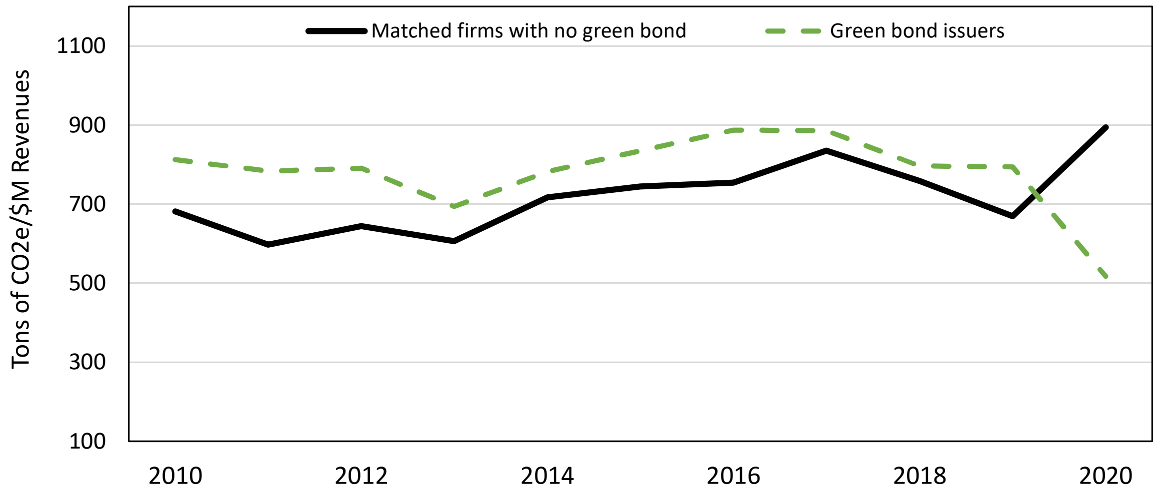
The table presents variations of regression (1) from Table 6. Except for regression (6), the dependent variable is a firm's carbon intensity. $OutVolume_{it}$ is the volume of a firm's green bonds outstanding at the end of year t, scaled by revenue. $GreeniumEffect_{it}$ is the cumulative pricing advantage (when positive, or else a disadvantage) that the issuance of green bonds has elicited relative to the issuance of brown bonds by year t. The sample covers the years 2010–2020. Except for regression (3), which uses all firms in the Refinitiv database, regressions include firms with green bond issues, as well as matched control firms. Standard errors (in parentheses) of the regression coefficients are estimated using clustering on two-digit SIC levels. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Winsorize at 1% and 99% levels	Use first lag of variables	Use all firms for regression	Use only reported CO2 (not estimated)	Use total assets for scaling	Use ENSCORE as dep. var.
	(1)	(2)	(3)	(4)	(5)	(6)
$Greenbond_{i,t-2}$	−106.59*	−60.69	−7.06	−70.72	−55.20	−2.17
	(52.75)	(58.39)	(30.74)	(55.96)	(32.57)	(2.41)
$OutVolume_{i,t-2}$	−4.50**		−1.60***	−1.82***	−1.80**	0.02*
	(1.66)		(0.59)	(0.52)	(0.69)	(0.01)
$GreeniumEffect_{i,t-2}$	−179.86**		−286.27	−187.70	−288.31*	6.70*
	(71.08)		(255.88)	(305.60)	(166.78)	(3.81)
$OutVolume_{i,t-1}$		−2.44**				
		(0.95)				
$GreeniumEffect_{i,t-1}$		−120.03**				
		(51.37)				
Company FE	YES	YES	YES	YES	YES	YES
CountryYear FE	YES	YES	YES	YES	YES	YES
IndustryYear FE	YES	YES	YES	YES	YES	YES
Observations	3,309	3,309	42,508	2,609	3,309	3,382
R-squared	0.92	0.94	0.89	0.96	0.94	0.91

Figure 1: Carbon intensity of green bond issuers and of matched firms with no green bonds over time

Carbon intensity is defined as CO2 emissions in tons scaled by revenue in USD millions. The sample comprises publicly listed non-financial corporates. Green bond issuers are firms that issued at least one green bond during the 2010–2020 period. Matched firms are firms in the same industry and country that are closest with respect to a set of firm-specific variables.

Panel A: Average carbon intensity by firm group (= equal-weighted average of firm-level carbon intensities)



Panel B: Total carbon intensity by firm group (= revenue-weighted average of firm-level carbon intensities)