Oxford Review of Economic Policy, 2023, **39**, 752–764
https://doi.org/10.1093/oxrep/grad040
Article

Green bonds and carbon emissions

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I am grateful to Pontus Braunerhjelm, Avraham Ebenstein, Isabel Ruiz, as well as conference participants at the workshop 'Combat Climate Change—The importance of innovation, entrepreneurship and new technology' in Stockholm for helpful comments and suggestions.

Abstract

This paper examines the relationship between green bonds (that is, bonds whose proceeds are committed to financing green projects) and carbon emissions at the aggregate level. Using data for US states, I find that the issuance of $1,000 of green bonds per capita is associated with a subsequent decrease in state-level emissions by 0.9–1.4 per cent. I obtain similar magnitudes using cross-country data. These results are stronger for green bonds that are certified by independent third parties, suggesting that certification is an important governance mechanism in the green bond market.

Keywords: green bonds, carbon emissions, sustainable finance, climate change

JEL classification: G23, M14, Q53, Q54

I. Introduction

Green bonds are bonds whose proceeds are committed to the financing of green projects (such as renewable energy, resource conservation, and the building of green facilities, among others). Green bond issuers include various entities such as corporations, municipalities, governments, and supranational organizations. The origin of the green bond market can be traced back to 2007, when the European Investment Bank (EIB) issued the very first green bond. Since then, the green bond market has grown rapidly. In October 2021, the cumulative issuance of green bonds crossed the threshold of $1 trillion (European Investment Bank, 2021).

Flammer (2020) documents several stylized facts pertaining to the green bond market. First, the main issuers of green bonds are located in China, France, and the United States. When looking at the growth of the green bond market across regions, Europe is clearly taking the lead, with North America following at a slower pace, and Asia showing a sharp increase in green bond issuance after 2015, which coincides with the year of the Paris Agreement (p. 110). Second, the issuance of green bonds differs across sectors. Governments (including supranational organizations) are the main issuers, followed by financial firms, utilities, industrial firms, and energy companies (p. 111).

The expansion of the green bond market is often seen as a step in the right direction in addressing climate change (e.g. Bloomberg, 2019). However, despite the rapid growth of this market, little is known of the effectiveness of green bonds in reducing emissions.

There are several reasons as to why green bonds may not substantially move the needle. First, the projects financed by green bonds may be too incremental to yield tangible reductions in emissions. Second, green bonds may not be 'green' to begin with. In this regard, concerns have been raised that green bonds could be prone to greenwashing—that is, issuers may issue green bonds to portray themselves as climate-friendly but without 'walking the talk' of improving their environmental footprint. These concerns are exacerbated by the fact that many green bond issuers operate in emission-intensive industries (Flammer, 2020). This greenwashing concern has received considerable attention among practitioners. For example, the *Financial Times* (2015) noted that '[a] few skeptical voices are starting to question the value of this innovation, asking in particular whether green bonds make any real difference or whether they are just another case of greenwashing', further highlighting that

> [a]ny company or municipality that wants to raise money by means of a green bond can do so, and all it has to do is convince the buyers it is justified. If those buyers are fund managers attempting to fill up their sustainable investment quota, they may not be motivated to be hypercritical.[1]

This greenwashing concern roots in the lack of public governance of the green bond market and hence the challenge of enforcing the 'greenness' of the bonds. In absence of public governance, the green bond market relies on private governance in the form of certification by independent third parties (such as the Climate Bonds Standard of the Climate Bonds Initiative and the Green Bond Principles of the International Capital Markets Association). These certifiers aim to mitigate information asymmetry and provide assurance that indeed the issuing entities are walking their talk and invest the proceeds of the green bonds into green projects. However, the criteria vary across certifiers, and concerns have been raised that the lack of unified standards may undermine the reliability of certification.[2]

As the above considerations illustrate, it is unclear to what extent, if any, green bonds help reduce emissions. In this article, I examine this question by studying the relationship between green bond issuance and emissions at the aggregate level. I study this relationship at both the state level (for the US green bond market) and country level (for the global green bond market). The analysis further evaluates the role of third-party certification as a private governance regime.

I start by documenting the growing popularity of green bonds in the US. In 2017 alone, the total issuance of green bonds in the US was $22 billion, out of which $9 billion was issued by corporations, $11 billion by municipalities, and $2 billion by government entities. There is considerable heterogeneity among US states. Using within-state variation, I then examine whether the issuance of green bonds is associated with a subsequent reduction in carbon emissions. My estimates indicate that state-level emissions decrease by 0.9–1.4 per cent following the issuance of $1,000 of green bonds per capita.

One important limitation of this analysis is that the issuance of green bonds is not random. Presumably, there are good reasons why the issuance of green bonds is more prevalent in certain states, and those reasons may correlate with unobservables that also affect emissions. In particular, it could be that certain states become more sensitive to climate change over time and take measures to reduce emissions. At the same time, as states become more eco-friendly, the pool of green investors may increase, which makes it more attractive to issue green bonds. In this case, I would observe a reduction in emissions following the issuance of green bonds, yet this relationship would be spurious as it is driven by unobservables.

To mitigate this issue, I conduct a series of tests. First, when I examine the dynamics, I find that the issuance of green bonds is associated with a subsequent reduction in emissions (not the other way around). If emissions were to decrease *before* the issuance of green bonds, this would be symptomatic of omitted variables. Second, to account for the possibility of (unobserved) local trends, I include the full set of regions by year fixed effects, thereby comparing states within the same broader region (e.g. Northeast). Third, I conduct a placebo test in which I use the green bond issuance of the neighbouring states as a placebo term. Arguably, nearby states are likely to be on similar trends in terms of eco-friendly attitudes. While the above tests mitigate the possibility that my results are driven by unobservables, I caution that they do not fully rule out endogeneity concerns. Doing so would require an instrument for the issuance of green bonds, yet—given the voluntary nature of green bond issuance—it is difficult to find such an instrument.

I then turn to certification. About two-thirds of green bonds in the US are certified by independent third parties. When I split the issuance of green bonds depending on whether they are certified versus non-certified, I find that the reduction in emissions is significantly larger for green bonds that are certified. This confirms that certification is an important governance tool in the green bond market.

Finally, I revisit the above results using country-level data. The estimates are broadly consistent with those I obtain for US states: I find that (i) the issuance of $1,000 of green bonds per capita is associated with a decrease in emissions by 1.4 per cent, and (ii) this relationship is significantly stronger for green bonds that are certified.

Overall, this study provides evidence for a negative relationship between green bond issuance and carbon emissions. This relationship is significantly stronger for green bonds that are certified by independent third parties,

[1] Relatedly, several examples of green bonds that turned out not to be green have been featured in the media (e.g. *Financial Times*, 2015, 2022).

[2] For instance, Park (2018) notes that '[i]n comparison to public regulation, private governance is often faster to implement and more responsive to the needs of market participants but may suffer from a lack of legitimacy, accountability, and consistency and be susceptible to greenwashing' (p. 1).

which highlights the importance of certification as a private governance mechanism in the (international) green bond market.[3]

This study contributes to several strands of the literature. First, it adds to the work by Flammer (2020, 2021) and Fatica and Panzica (2021) who study how the issuance of corporate green bonds affects firm-level outcomes. These articles find that issuers tend to improve their environmental performance following the issuance of green bonds, especially when the green bonds are certified by independent third parties.[4] While these studies indicate that green bonds may play a role in reducing firm-level emissions, they need not imply that green bonds matter in the aggregate. For example, it could be that the green bonds considered in these studies finance green projects that are unlikely to move the needle at more aggregated levels. Or it could be that a substitution takes place between the emissions of different entities. By considering all green bonds (issued by corporations, municipalities, and governments) and emissions at the state and country level, this study moves beyond the firm level and sheds light on the relationship between green bonds and the overall level of emissions. Second, this study adds to the literature on impact investing that examines how financial instruments can contribute to environmental and social objectives (e.g. Geczy *et al*., 2021; Boulongne *et al*., 2023; Flammer *et al*., 2023). Finally, this paper contributes to the literature that examines how climate finance can help address climate change and other grand challenges (e.g. Kotchen and Negri, 2016; Kotchen and Costello, 2018).

The remainder of this paper is structured as follows. Section II presents the data; section III describes the methodology; section IV presents the results; finally, section V offers conclusions.

II. Data

(i) Green bonds

The green bond data are obtained from Bloomberg. For the main analysis, I restrict the Bloomberg universe to US securities. (I describe the international green bond data in section III(iv).) Bloomberg distinguishes between corporate bonds and government bonds.[5,6] For both asset classes, I extract all bonds that are labelled as green (this is done by setting *green bond indicator* = 'yes' in Bloomberg). One caveat of the Bloomberg data is that the corporate asset class includes several government entities. To correct for this, I reassign as government bonds all corporate bonds for which *BICS classification* = 'government'.

In addition to corporate and government bonds, Bloomberg also covers municipal bonds ('muni bonds'). Bloomberg does not maintain a green bond indicator variable for muni bonds. Instead, I rely on the variable *municipal bond purpose* to identify those that qualify as green muni bonds.

In Figure 1, I plot the issuance of green bonds (aggregating the issuance amount) over time for each of the three asset classes (corporate, municipal, and government bonds). The pattern is consistent with the rapid expansion of the green bond market mentioned above. Over a 10-year period, the issuance of green bonds soared to reach $22 billion in 2017, out of which $9 billion was issued by corporations (41 per cent), $11 billion by municipalities (50 per cent), and $2 billion (9 per cent) by government entities.

For each green bond, Bloomberg records the state of the issuer. Panel A of Figure 2 plots the issuance of green bonds by state (darker-shaded areas represent higher issuance amounts). As can be seen, there is considerable variation across states without a clear concentration in specific areas. This variation lends itself to the state-level analysis I describe in section III.

Finally, Panel B of Figure 2 paints a similar picture, using the issuance of green bonds per capita. The data on population (at the state-year level) are obtained from the Federal Reserve Economic Data of the St Louis Fed (FRED).

(ii) Emissions

The emission data are obtained from the US Energy Information Administration (EIA) for each state and year until 2016. (These data are described in detail in Energy Information Administration (2019).)

Figure 3 plots the evolution of the volume of emissions—measured in millions of metric tons of carbon dioxide (CO_2)—across all states from 2000 to 2016. As is shown, emissions are declining post-2007. Interestingly, this

[3] Naturally, this does not imply that certification is *the* most effective governance regime for the green bond market. See Flammer (2020) and Park (2018) for a discussion of this point.

[4] Ehlers *et al*. (2020) find no significant relationship between green bonds and firm-level emissions, but do not differentiate between certified and non-certified green bonds. Based on their finding, they highlight the need for properly designed ratings of the 'greenness' of the bonds.

[5] Bloomberg includes a series of other fixed income securities—such as loans and asset-backed securities (ABS)—that can be marked as 'green' as well. Since these are not bonds *per se*, I do not include them in the analysis.

[6] See Flammer (2021) for a detailed description of the corporate green bond market.

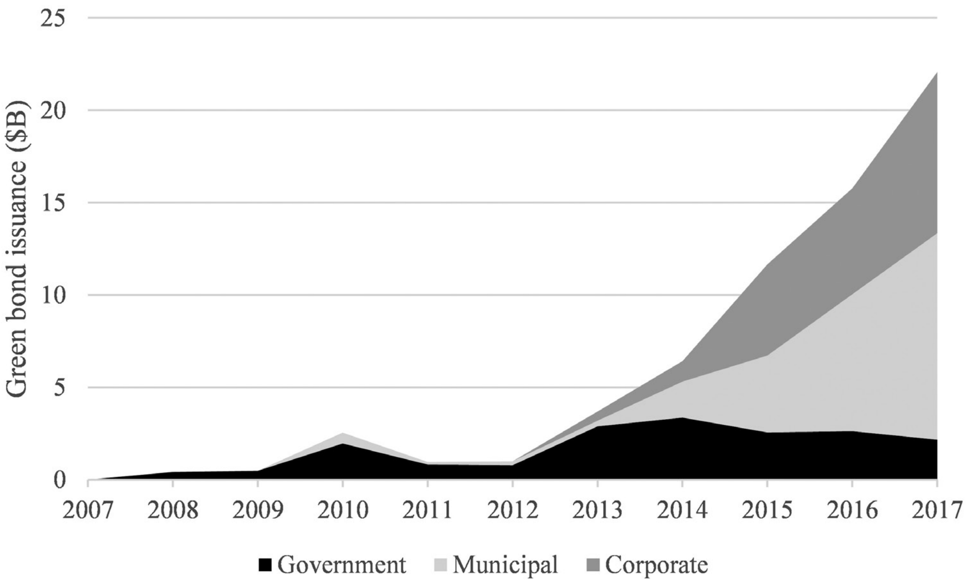

Figure 1: Green bond issuance in the US. *Notes*: This figure plots the evolution of the total amount (in $ billions) of green bond issuance in the US. The data are presented by issuer type (government, municipal, and corporate).

decrease coincides with the growth of the green bond market. Naturally, this correlation need not imply that the issuance of green bonds was instrumental in the decrease in emissions. Yet, this pattern is worth noting.

Figure 4 describes the heterogeneity across states. Panel A plots the total volume of emissions in metric tons by state, while Panel B plots the per capita figures. There is again considerable heterogeneity across sates. The state with the highest emissions per capita is Wyoming (with an average of 120 metric tons of CO_2 per capita).[7] At the other end of the spectrum, the lowest emissions per capita are found in the District of Columbia (with an average of 5.5 metric tons of CO_2 per capita).

(iii) Summary statistics

Table 1 provides summary statistics for the variables used in the analysis. The sample includes all 50 states (as well as the District of Columbia) from 2001 to 2016.[8] Accordingly, the number of state-year observations is 51 × 16 = 816.

Panel A reports summary statistics for the full sample. As can be seen from Panel A, the average population is about 6 million, the average volume of emissions is 110 million metric tons of CO_2 (24 metric tons per capita), and the average state GDP is $284 billion ($48,000 per capita).[9]

Panel B restricts the sample to state-year observations with non-zero green bonds. The average volume of green bond issuance is $328 million ($216 per capita), out of which $94 million are corporate bonds, $113 million municipal bonds, and $121 million government bonds.

III. Methodology

(i) Baseline specification

To examine whether CO_2 emissions decrease following the issuance of green bonds, I estimate the following regression:

[7] This is consistent with Energy Information Administration (2019, p. 3) noting that Wyoming has fewer than 600,000 people, giving Wyoming the lowest population density. Its winters are cold (the average low temperatures in January range between 5 and 10 degrees Fahrenheit). These factors raise Wyoming's per capita CO_2 emissions compared with other states.

[8] The relevant data are from 2000 to 2016, but one year is dropped in the regressions since right-hand side variables are lagged by one year (see section III).

[9] The state-level GDP data are obtained from the US Bureau of Economic Analysis (BEA).

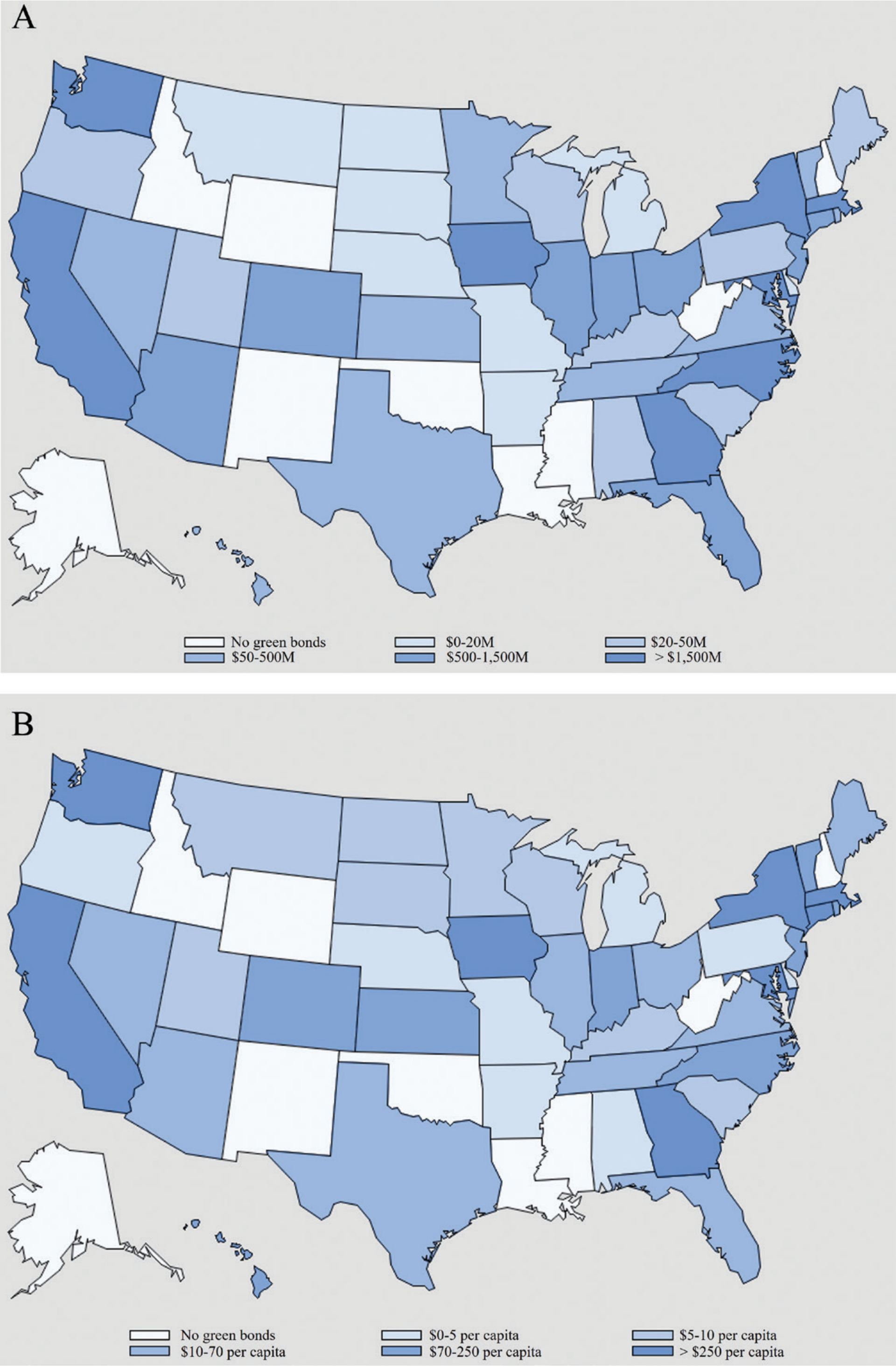

Figure 2: Green bond issuance by state. *Notes*: This figure reports the issuance of green bonds by US state. In Panel A, darker-shaded areas represent higher issuance amounts (in $ million, sum across all years). In Panel B, darker-shaded areas represent higher issuance amounts per capita (in $ per capita).

Figure 3: Carbon emissions in the US. *Note*: This figure plots the evolution of total carbon emissions, measured in millions of metric tons of carbon dioxide (CO_2) in the US.

$$\begin{aligned} log(emissions)_{st} &= \alpha_s + \alpha_t + \alpha_r \times \alpha_t \\ &+\beta \times green\ bonds_{st-1} + \gamma \mathbf{X}_{st-1} + \varepsilon_{st}, \end{aligned} \quad (1)$$

where s indexes states, t indexes years, and r indexes Census regions (Northeast, Midwest, South, and West); α_s, α_t, and $\alpha_r \times \alpha_t$ are state, year, and region by year fixed effects, respectively; *log(emissions)* is the natural logarithm of the metric tons of CO_2 in the state; *green bonds* is the dollar amount of green bond issuance (in $1,000) per capita in the state (in the preceding year); **X** is the vector of control variables which includes *log(population)* and *GDP per capita* at the state level (in the preceding year); and ε is the error term.[10] Given that the variation in *green bonds*—which, in spirit, represents the 'treatment' variable—is at the state level, I cluster standard errors at the state level throughout (Bertrand *et al*., 2004).

The inclusion of state fixed effects accounts for (time-invariant) unobserved heterogeneity at the state level that could confound the relationship between *green bonds* and *log(emissions)*. The year fixed effects account for economy-wide factors (such as macroeconomic shocks or economy-wide trends in environmental consciousness) that could affect both variables. The state-level controls in **X** further account for changes in the state's business environment.

(ii) Identification

A key challenge with regression (1) is the endogeneity of green bond issuance. Indeed, the decision to issue green bonds may correlate with unobservables that also affect CO_2 emissions. In particular, a key alternative could be that US states are on different trends in terms of eco-friendly attitudes. States that become more eco-friendly may take actions to improve their environmental footprint. At the same time—as states become more eco-friendly—local investors might be more inclined to invest in green financial instruments, which is conducive to the issuance of green bonds. Such alternatives would be consistent with my finding of a negative relationship between green bond issuance and emissions.

While such an alternative interpretation cannot be ruled out—doing so would require a source of (quasi-)exogenous variation in green bond issuance—it is unlikely to explain my results, for several reasons. First, when I examine the dynamics, I find that the issuance of green bonds is associated with a subsequent reduction in

[10] Note that I express green bonds on a per capita basis to make it comparable across states of different sizes. An alternative would to be use *log(green bonds)*—such that β would have the convenient interpretation of an elasticity. Yet, *green bonds* is 0 for many state-year observations, which complicates the use of a log-log specification.

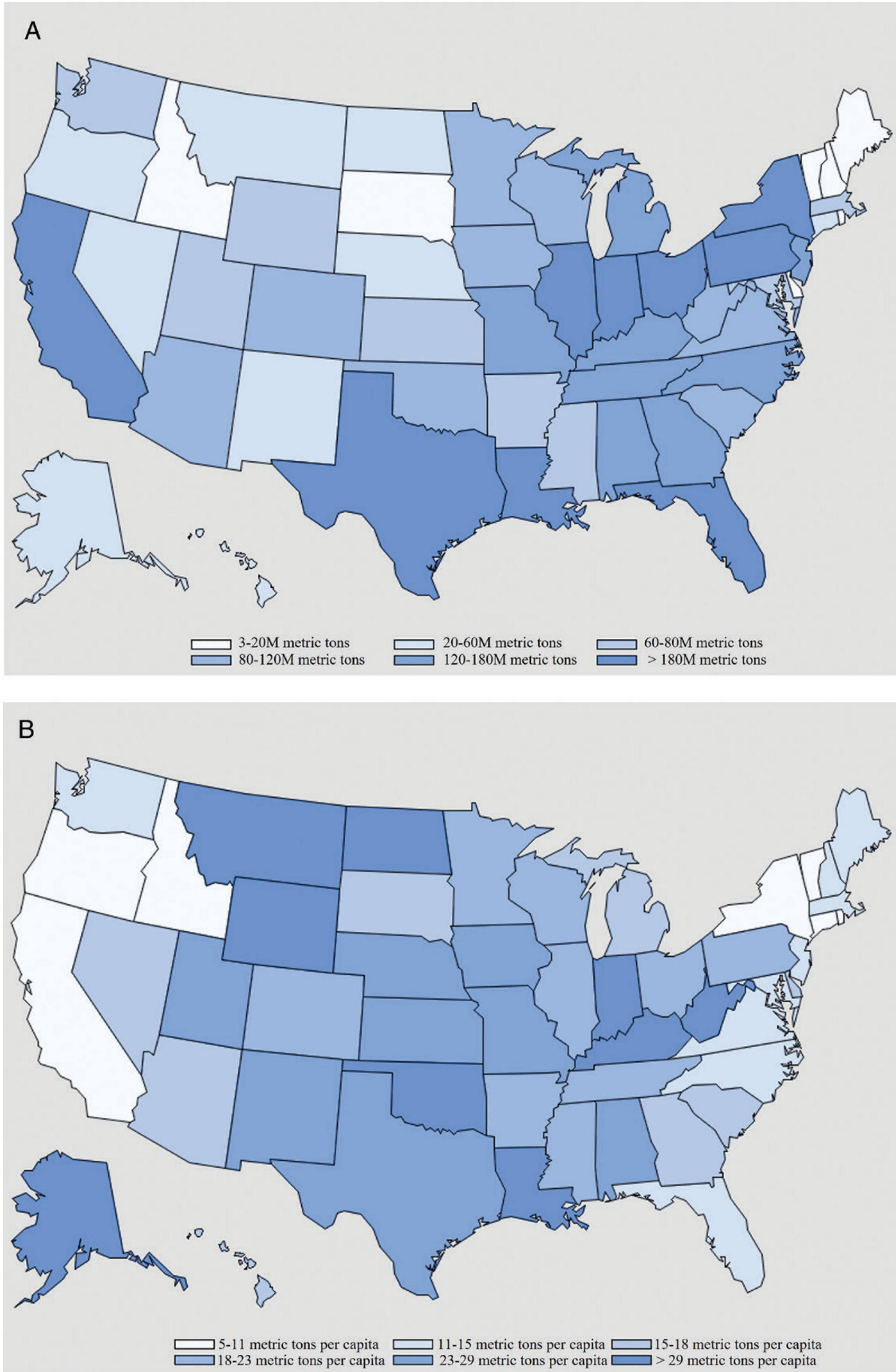

Figure 4: Carbon emissions by state. *Notes*: This figure reports carbon emissions by US state. In Panel A, darker-shaded areas represent higher emissions (in millions of metric tons of CO_2, average across all years). In Panel B, darker-shaded areas represent higher emissions per capita (in metric tons of CO_2 per capita).

Table 1: Summary statistics

Panel A. All state-year observations (2001–16)					
Variable	**Obs**	**Mean**	**Std Dev**	**Min**	**Max**
Populations (million)	816	5.97	6.69	0.49	39.21
Green bonds ($ million)	816	52.61	296.56	0.00	3,710.95
Municipal ($ million)	816	18.08	106.95	0.00	1,554.16
Corporate ($ million)	816	15.06	139.24	0.00	2,469.63
Government ($ million)	816	19.48	216.75	0.00	3,360.95
Green bonds ($ per capita)	816	34.81	342.32	0.00	5,601.33
Emissions (millions of CO_2 metric tons)	816	110.35	106.96	3.00	660.00
Emissions per capita (CO_2 metric tons per capita)	816	23.87	19.40	4.37	129.38
GDP ($ million)	816	284,460	356,949	18,661	2,665,349
GDP per capita ($)	816	48,039	19,508	23,494	189,450

Panel B. State-year observations with non-zero green bond issuance					
Variable	**Obs**	**Mean**	**Std Dev**	**Min**	**Max**
Populations (million)	131	9.06	8.91	0.58	39.21
Green bonds ($ million)	131	327.72	678.61	0.38	3,710.95
Municipal ($ million)	131	112.60	246.94	0.00	1,554.16
Corporate ($ million)	131	93.80	337.79	0.00	2,469.63
Government ($ million)	131	121.32	531.11	0.00	3,360.95
Green bonds ($ per capita)	131	216.82	833.59	0.02	5,601.33
Emissions (millions of CO_2 metric tons)	131	128.86	111.95	3.00	657.00
Emissions per capita (CO_2 metric tons per capita)	131	15.55	8.64	4.37	78.82
GDP ($ million)	131	515,267	541,759	30,673	2,665,349
GDP per capita ($ per capita)	131	63,005	32,777	37,856	189,450

Note: This table reports summary statistics. Panel A includes all state-year observations from 2001 to 2016. Panel B restricts the sample to state-year observations with non-zero green bond issuance.

emissions (not the other way around). If emissions were to decrease before the issuance of green bonds, this would be symptomatic of latent (unobservable) trends such as a shift in eco-friendly attitudes at the local level.

Second, in regression (1), I include the full set of region by year fixed effects ($\alpha_r \times \alpha_t$). The granularity of the data—and the fact that green bonds do not cluster in specific regions (see Figure 2)—allows for this tighter inference. Intuitively, these fixed effects account for any latent trend at the regional level.

Third—and related to the previous point—I conduct a placebo test in which I use as right-hand side variable the green bond issuance of neighbouring states. If the issuance of green bonds simply proxies for (unobservable) local trends in eco-friendly attitudes, I would likely observe that green bond issuance in neighbouring states predicts emission reductions in the state in question. However, when I conduct this test, I find that the placebo term is insignificant (see section IV(i) for details).

Fourth, I document in section IV(ii) that the relationship between *green bonds* and *emissions* is significantly stronger for green bonds that are certified by independent third parties. If my results were driven by unobservables, such unobservables would need to explain not only (i) the negative relationship between green bonds and emissions, but also (ii) the heterogeneity in terms of certified versus non-certified green bonds. It is difficult to think of omitted variables that would (plausibly) explain this set of results.

(iii) Certification

In regression (1), all bonds that are listed as 'green' in Bloomberg enter the calculation of *green bonds* at the state level. Yet, not all green bonds are certified by independent third parties.

To distinguish between certified and non-certified green bonds, I use the certification information provided in the Climate Bonds Initiative (CBI) database.[11] This database compiles information on the certification of each green bond, along with the identity of the third-party certifier. Common certifiers include Sustainalytics, Vigeo Eiris, Ernst & Young, and CICERO (Center for International Climate Research). Green bonds can be issued under a variety of voluntary standards. Two leading standards that verify the integrity of the green bond label are the Green Bond Principles (GBP) and the Climate Bond Standards (CBS). In a nutshell, the certification process is split into two phases. In the pre-issuance phase, the certifier verifies that (*a*) the projects to be financed by the bond proceeds are eligible under the specific certification standards, and (*b*) the issuer has established internal processes and controls to keep track of how the bond proceeds are used (which includes the submission of annual reports). In the post-issuance phase, the certifier verifies that the proceeds have been allocated to green projects in accordance with the standards.

Using the certification information, I split *green bonds* from regression (1) into two variables: *green bonds (certified)* and *green bonds (not certified)*. I then estimate the following variant of regression (1):

$$\begin{aligned} log(emissions)_{st} = {} & \alpha_s + \alpha_t + \alpha_r \times \alpha_t + \beta_1 \times green\ bonds\ (certified)_{st-1} \\ & + \beta_2 \times green\ bonds\ (not\ certified)_{st-1} + \gamma \mathbf{X}_{st-1} + \varepsilon_{st}. \end{aligned} \tag{2}$$

If certification moderates the relationship between green bonds and carbon emissions, I should observe a significant difference between $\beta 1$ and $\beta 2$.

(iv) Country-level regressions

In auxiliary analyses, I conduct variants of the state-level analysis described above, but at the country level. The data and methodology are analogous.

The green bond data are again obtained from Bloomberg. I aggregate the amount of green bond issuance for each country and year (all amounts are converted into US dollars).[12] The emission data (along with the data on population and GDP) are obtained from the *OECD.Stat* database maintained by the OECD. The database covers all OECD countries, along with selected non-OECD economies (such as Argentina, Brazil, and China). The data are not available for each country and year. After discarding the missing data, I obtain a final sample of 253 country-year observations from 2005 to 2016.

Using these data, I estimate a variant of regression (1) at the country level. Specifically, I estimate the following specification:

$$log(emissions)_{ct} = \alpha_c + \alpha_t + \beta \times green\ bonds_{ct-1} + \gamma \mathbf{X}_{ct-1} + \varepsilon_{ct}, \tag{3}$$

where c indexes countries, and t indexes years; α_c and α_t are country and year fixed effects, respectively; *log(emissions)* is the natural logarithm of the metric tons of CO_2 at the country level; *green bonds* is the dollar amount of green bond issuance (in \$1,000) per capita at the country level (in the preceding year); $\mathbf{X}$ is the vector of control variables which includes *log(population)* and *GDP per capita* at the country level (in the preceding year); and ε is the error term. Standard errors are clustered at the country level.

Finally, to examine whether certification matters at the country level, I estimate the country-level equivalent of regression (2):

$$\begin{aligned} log(emissions)_{ct} = {} & \alpha_c + \alpha_t + \beta_1 \times green\ bonds\ (certified)_{ct-1} \\ & + \beta_2 \times green\ bonds\ (not\ certified)_{ct-1} + \gamma \mathbf{X}_{ct-1} + \varepsilon_{ct}. \end{aligned} \tag{4}$$

IV. Results

(i) Main results

The main results are presented in Table 2. Columns (1) and (2) report estimates of the regression in equation (1). The specification in column (1) includes state and year fixed effects, while the specification in column (2) further includes the full set of Census region × year fixed effects to account for unobservable trends at the regional level. As can be seen, the estimate of β lies between –0.009 and –0.014 and is statistically significant at conventional levels (with t-statistics ranging from 2.08 to 4.05). This implies that the issuance of \$1,000 of green bonds per capita is

[11] For details, see Flammer (2020, 2021).

[12] Municipality bonds are only available for the US. Hence, this analysis is restricted to the other two asset classes (corporate bonds and government bonds).

Table 2: Main results

Dependent variable:	Log(emissions)$_t$		
	(1)	(2)	(3)
Green bonds$_{t-1}$	–0.014***	–0.009**	–0.008**
	(0.003)	(0.004)	(0.004)
Green bonds (placebo)$_{t-1}$			–0.002
			(0.006)
Controls	Yes	Yes	Yes
Year fixed effects	Yes	–	–
State fixed effects	Yes	Yes	Yes
Region × year fixed effects	No	Yes	Yes
Within R^2	0.123	0.088	0.090
Observations	816	816	816

Notes: The unit of observation is state-year. The dependent variable *log(emissions)* is the natural logarithm of the million metric tons of CO_2. *Green bonds* is the amount of green bond issuance (in $1,000 per capita) in the previous year. *Green bonds (placebo)* is the average of *green bonds* in the neighbouring states. Control variables include log(population) and log(GDP) at the state level, lagged by one year. Regions are the four Census regions (Northeast, Midwest, South, and West). The sample period is 2001–16. Standard errors (in parentheses) are clustered at the state level. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

associated with a subsequent decrease in state-level emissions by 0.9–1.4 per cent. Since the average state population is 6 million, and the average volume of emissions is 110 million metric tons of CO_2 (see Table 1), this implies that the issuance of green bonds in the amount of $6 billion (= $1,000 × 6 million) corresponds to an average reduction in emissions by 0.99 million (= 0.009 × 110 million) to 1.54 million (= 0.014 × 110 million) metric tons of CO_2 at the state level. Equivalently, this implies that an issuance of green bonds in the amount of $1 million corresponds to an average reduction in emissions by 165–257 metric tons of CO_2 at the state level.

The specification in column (3) implements the placebo test discussed in section III(ii). Specifically, I augment the baseline specification used in column (2) by including as additional control the average of *green bonds* across all neighbouring states. If the issuance of green bonds merely proxies for (unobservable) local trends in eco-friendly attitudes, I might observe that the issuance of green bonds in neighbouring states predicts emission reductions in the state in question. Nevertheless, the coefficient of the placebo term is small and insignificant, which is inconsistent with this interpretation.

To further validate this placebo test, Figure 5 plots the evolution of *log(emissions)* in the 'green bond states' vs neighbouring 'non-green bond states' around the year in which the green bond states had their first issuance of green bonds (year 0). As can be seen, the two sets of states are on a similar trend prior to the green bond issuance, which suggests that the neighbouring states may provide an informative counterfactual. After the initial issuance of green bonds in the green bond states, the two groups' emissions start to diverge substantially.[13]

(ii) Certification

Table 3 presents a variant of the baseline specification in column (2) of Table 2, but decomposing *green bonds* depending on whether the bonds are certified or not by independent third parties. This corresponds to the regression specification in equation (2).

As can be seen, the reduction in emissions is substantially larger for green bonds that are certified. The coefficients of –0.012 and –0.003, respectively, imply that state-level emissions decrease by 1.2 per cent following the issuance of $1,000 of certified green bonds per capita, while the decrease is only 0.3 per cent for non-certified green bonds. The difference between the two coefficients is significant in statistical terms (p-value = 0.034). Overall, this evidence indicates that certification plays an important role in the green bond market.

(iii) Country-level evidence

Table 4 presents the results of the country-level regressions. Column (1) reports estimates corresponding to the specification in equation (3), while column (2) reports estimates pertaining to the specification in equation (4).

[13] In the pre period (years $t = –3$ to $t = –1$), the average difference in emissions between the two groups is insignificant with a p-value of 0.931. In the post period (years $t = 0$ to $t = 3$), the difference is significant at conventional levels with a p-value of 0.013.

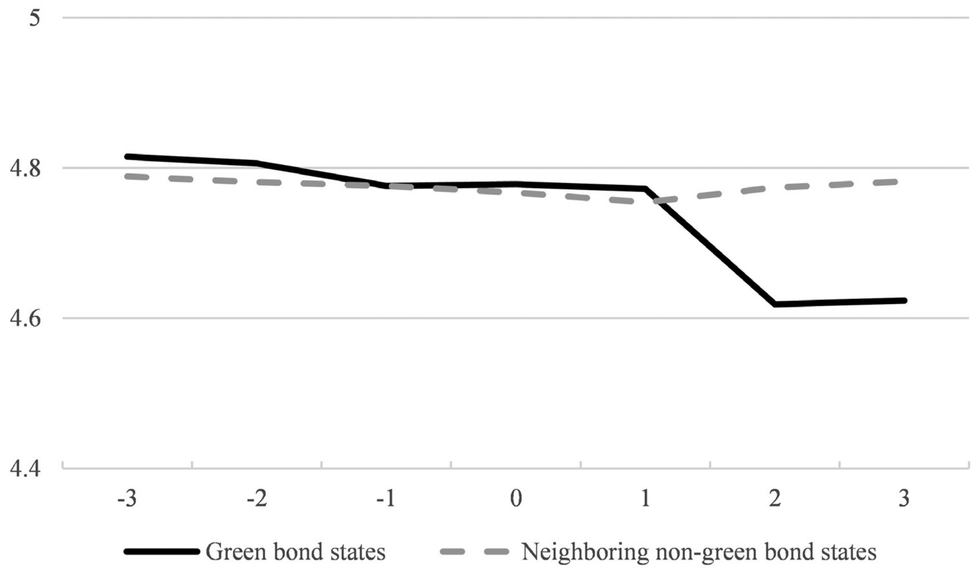

Figure 5: Dynamics. *Notes*: This figure plots the average of *log(emissions)* in the 'green bond states' (black solid line) and neighbouring 'non-green bond states' (grey dashed line) on an annual basis from $t = -3$ until $t = 3$, where $t = 0$ refers to the year of the green bond issuance in the respective green bond state. The mean of the non-green bond group is normalized to match the mean of the green bond group at $t = -1$.

Table 3: Certification

Dependent variable:	**Log(emissions)$_t$**
Green bonds (certified)$_{t-1}$	–0.012***
	(0.004)
Green bonds (not certified)$_{t-1}$	–0.003
	(0.005)
Controls	Yes
State fixed effects	Yes
Region × year fixed effects	Yes
Within R^2	0.101
Observations	816

Notes: The table presents a variant of the baseline specification in column (2) of Table 2, splitting *green bonds* depending on whether the bonds are certified or not by independent third parties. The sample period is 2001–16. Standard errors (in parentheses) are clustered at the state level. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The estimate of β in column (1) is –0.014 (t-statistic = 2.85), which implies that the issuance of $1,000 of green bonds per capita is associated with a subsequent decrease in emissions by 1.4 per cent at the country level. This estimate is in the ballpark of what I obtained in the state-level regressions of Table 2.

Finally, column (2) distinguishes between certified versus non-certified green bonds. A similar pattern emerges as in Table 3: (i) the point estimate is larger (and only significant) for certified green bonds, and (ii) the difference between the two coefficients is significant (p-value = 0.055). This further confirms the importance of certification as a private governance mechanism in the (international) green bond market.

V. Conclusion

Addressing climate change is perhaps the greatest challenge faced by our and future generations. The United Nations' Intergovernmental Panel on Climate Change estimates that limiting global warning to less than 2°C—the

Table 4: International evidence

Dependent variable:	**Log(emissions)$_t$**	
	(1)	**(2)**
Green bonds$_{t-1}$	–0.014***	
	(0.005)	
Green bonds (certified)$_{t-1}$		–0.017***
		(0.006)
Green bonds (not certified)$_{t-1}$		–0.006
		(0.006)
Controls	Yes	Yes
Year fixed effects	Yes	Yes
Country fixed effects	Yes	Yes
Within R^2	0.054	0.078
Observations	253	253

Notes: The table presents variants of the regressions in Tables 2 and 3, using OECD countries (in lieu of US states). The unit of observation is country-year. The sample period is 2005–16. Standard errors (in parentheses) are clustered at the country level. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

stated objective of the Paris Agreement of 2015—requires investments of about $3 trillion per year until 2050 (World Economic Forum, 2021). Accordingly, achieving this objective requires massive amounts of funding. This tremendous financing need calls for private solutions in addition to governments' efforts to combat climate change.

This paper examines a potentially promising instrument: green bonds—i.e. bonds whose proceeds are committed to the financing of green projects. Since the inaugural green bond issued by the European Investment Bank in 2007, green bonds have become increasingly popular among private investors, and practitioners often refer to this evolution as the 'green bond boom' (Morgan Stanley, 2017). This study examines the relationship between green bonds and carbon emissions at the aggregate level. Using data for US sates, I find that the issuance of $1,000 of green bonds per capita is associated with a subsequent decrease in state-level emissions by 0.9–1.4 per cent. I obtain similar magnitudes using cross-country data. These results are significantly stronger for green bonds that are certified by independent third parties, suggesting that certification is a key governance mechanism for green bonds.

This study is subject to two main limitations. First, the results are correlational. While I conduct several robustness tests to mitigate endogeneity concerns, I caution that my results need not warrant a causal interpretation. Second, this study does not shed light on the specific mechanisms through which issuers decrease their environmental footprint (e.g. through technological innovation, changes in business practices, adjustments in their governance). More research is needed to characterize the relevant mechanisms. Doing so would require more granular data at the project level.

Overall, my findings suggest that green bonds can be a potentially powerful tool in the fight against climate change. Yet, they also indicate that, in the absence of public governance, (i) certification serves as an important governance mechanism, and (ii) greenwashing concerns remain for non-certified bonds. An important insight of these findings is that the (current) lack of public governance is likely sub-optimal and several challenges remain in the green bond market.[14] For example, (i) the ambiguous definition of 'green' likely complicates certification; (ii) the existence of multiple taxonomies (e.g. GBP and CBS) and hence a lack of universal rules and standardization may impede the effectiveness, efficiency, and integrity of the market; (iii) the informativeness of the current binary certification (either a bond is certified or not) is limited and a tiered rating system would likely provide more information (in this spirit, Ehlers *et al*. (2020) advocate for the introduction of a rating system at the firm level); and (iv) there is currently no requirement of 'additionality' in the green bonds market—that is, companies can label their bonds as green even if they would have undertaken the green projects anyway without the issuance of a green bond. The latter raises the question of whether additionality should be a criterion for certification. In sum, and as this discussion illustrates, the lack of public governance is likely sub-optimal; more research and policy discussion are needed to improve the governance of the green bond market.

[14] See Flammer (2020) for a related discussion.

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