GREEN BONDS, AIR QUALITY, AND MORTALITY

EVIDENCE FROM THE PEOPLE'S REPUBLIC OF CHINA

Yan Luo, Shu Tian, and Hao Yang

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ABSTRACT

In this paper, we examine whether and how green bond issuance affects local air quality and mortality rates in the People's Republic of China. We find that a 1 standard deviation increase in corporates' green bond financing in a city is associated with a 0.6% reduction in local air pollution generally and an 0.8% reduction in $PM_{2.5}$, which refers to tiny pollutant particles with a size of less than 2.5 microns. The effect is stronger when certified green bonds are examined and in cities with higher gross domestic product growth. Further, the green bond financing prevalence is also significantly and negatively associated with local mortality rates, which is consistent with our expectation that, by improving local air quality, green bond issuance helps to enhance local residents' health. The findings are robust to the control of a set of potential determinants of air quality, and a series of robustness tests confirm that the effects are not simply driven by endogeneity.

Keywords: green bonds, air quality, mortality

JEL codes: G19, G12

I. INTRODUCTION

In this study, we examine the environmental outcomes of green bond issuance, focusing on the improvements in local air quality, and investigate two interrelated research questions. The first research question is whether green bond issuance helps to improve local air quality. The second research question is, if green bond issuance indeed helps to improve local air quality, does it also help to improve local residents' health conditions as a consequence?

Green bonds are debt instruments specifically designed to support specific climate-related or environmental projects, such as renewable energy, energy efficiency, mitigation of climate change impacts, and resource conservation. The issuance of green bonds is becoming more and more popular in recent years, given society's growing concerns about the environment and the widespread interest in sustainable finance. In 2019, 12 years after the European Investment Bank issued the first green bond in 2007 (Tang and Zhang 2020), global green bond issuance surpassed $250 billion, accounting for about 3.5% of total global bond issuances (Ehlers, Mojon, and Packer 2020).

Although green bond issuance has gained much attention, its real impact on environmental performance is under-investigated and inconclusive in existing literature. Some argue that companies use green bond issuance as a credible signal of their commitment toward the environment. Therefore, even if the proceeds collected from the issuance of green bonds may not be large enough to bring significant changes in environmental outcomes, green bond-issuing firms' commitment materializes in eco-friendly behavior, which is likely to be followed by improvements in environmental performance. However, very few studies have provided direct evidence on such improvements. Flammer (2021) is one of the few that empirically show how green bond issuance has led to increased environmental ratings and reduced carbon dioxide emissions. Other existing studies that support this signaling argument mainly focus on the capital market reaction, and contend that green bond issuance provides a credible signal of companies' commitment to the environment because there is a positive stock market reaction to the announcement of green bond issuance (e.g., Flammer 2021, 2015, and 2013; Tang and Zhang 2020; Krueger 2015; Klassen and McLaughlin 1996). However, some contend that companies may use green bonds as a tool for "greenwashing", that is, to make unsubstantiated or misleading claims about their commitment to the environment and simply issue green bonds to portray themselves as environmentally responsible, while they are actually not. In such cases, green bond issuance should have no impact on environmental performance (e.g., Berrone, Fosfuri, and Gelabert 2017; Lyon and Montgomery 2015; Marquis, Toffel, and Zhou 2016).

We join the recent debate on whether green bond issuance serves as a credible signal of commitment to the environment or simply represents a suitable greenwashing strategy. In doing so, we focus on the environmental outcomes following green bond issuance. More specifically, we examine whether and how green bond issuance affects local air quality. We conduct the investigation at the city level in the People's Republic of China (PRC), which has the largest market for green bonds in terms of total issuance amount, at $75.1 billion (Flammer 2021).

We collect monthly data on green bond issuance, as a fraction of total bond issuance, at the city level, and match it to air quality data 1 year ahead. We collect a series of air quality data from the China Meteorological Data Service Center, including air quality index (AQI), which is an inverse indicator of air quality, as well as the emission of fine particulate matters ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), sulfur oxide (SO_2), and nitrogen oxide (NO_2). We find that green bond financing is negatively associated with all of these air quality measures, and the relation is significantly different from zero when AQI and $PM_{2.5}$ are examined. A 1 standard deviation increase in green bond financing is associated with a 0.6% reduction in AQI and an 0.8% reduction in $PM_{2.5}$ emission, confirming that green bond issuance is followed by air quality improvements, which are statistically and economically significant. The findings are robust when controlling for local economic activities and weather conditions, which are typical confounders in estimating the air pollution effect, as well as for city and time fixed effects. Robustness checks, such as the change on change regression and Generalized Method of Moments (GMM) model regressions, confirm that the causality runs from green bond issuance to air quality improvements, rather than the other direction. And we find that the effect is especially evident when certified green bonds are examined or in cities with higher gross domestic product (GDP) growth.

We take one further step to examine the impact of green bond financing on local residents' health conditions. A number of studies have suggested that air pollution has significant and negative impacts on residents' health conditions, and thus is positively associated with local mortality rates (e.g., He, Liu, and Zhou 2020; Sheldon and Sankaran 2017; Currie and Neidell 2005; Chay and Greenstone 2003). If green bond issuance helps to improve local air quality, we also expect it to be significantly related with local mortality rates. Consistently, we find that green bond issuance is significantly and negatively associated with local mortality rates 1 year ahead, confirming that green bond issuance, by improving local environments, also exhibit positive impacts on residential well-being.

Our study contributes to the literature in more ways than one. First, very few studies have directly examined the environmental outcomes of green bond financing. We join Flammer (2021) by providing such evidence. To our knowledge, we are the first to present empirical evidence on the influence of green bond issuance on local air quality at the city level, which adds to the literature on the real impacts of green bond issuance in terms of reducing air pollution. We also show that green bond issuance, by improving local air quality, helps to enhance residents' health conditions, which is reflected in reduced mortality rates. Second, our study adds to the debate over whether green bond issuance is a credible signal of corporates' commitment to be environmentally responsible or a tool for greenwashing. We document pieces of evidence that support the signaling argument. It is consistent with Flammer's (2021) argument that issuing green bonds is costly to firms, and thus it need not represent a suitable greenwashing strategy. Further, we show that certified green bond issuance, which is even costlier to issuers as it has to undergo third-party verification to establish that the proceeds are funding projects that generate environmental benefits, displays stronger effects in terms of improving local air quality. Lastly, although the PRC is now the largest green bond issuance market, it only started issuing green bonds in 2015, and thus very few studies have investigated green bond financing in the PRC. Our study attempts to fill this void, and our findings can help market participants to better understand the effects of green bond financing in emerging markets.

The rest of the paper is organized as follows. In section II, we discuss the related literature and develop our research hypotheses. In section III, we introduce our data and methodologies. Sections IV and V present our empirical findings about the influence of green bond issuance on local air quality and mortality rates, respectively. Section VI concludes.

II. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

A. Green Bond Issuance: Signaling versus Greenwashing

There is an ongoing debate on whether green bond issuance brings about environmental improvements. Flammer (2021) contends that it is possible that corporates issue green bonds, which are costly to issuers, to (i) send a credible signal to investors and other interested stakeholders that they are committed towards the environment; or (ii) engage in greenwashing, that is to mislead investors or other stakeholders that they are environmentally responsible, yet do not take tangible actions. Thus, whether green bond issuance is a reliable signal or simply a greenwashing strategy in general is a pure empirical question.

Flammer (2021) conjectures that, although proceeds from green bond issuance are committed to green projects, the green bonds themselves are likely to be too small to bring significant environmental improvements. However, by issuing green bonds, corporates are sending out a costly and, thus, credible signal about their commitment to eco-friendly behavior, which is likely to be followed by improved environmental performance. However, there are also studies that support the greenwashing argument, suggesting that corporates are likely to issue green bonds without having tangible environmentally responsible actions (e.g., Berrone, Fosfuri, and Gelabert 2017; Lyon and Montgomery 2015; Marquis, Toffel, and Zhou 2016).

Existing studies on the effect of green bond financing mainly focus on capital market reactions to the issuance. Klassen and McLaughlin (1996) show that firms' receipt of environmental awards is followed by significant increases in their stock prices. Baker, Bergstresser, Serafeim, and Wurgler (2018) find that green municipal bonds are issued at a premium to otherwise similar ordinary bonds, which indicate that investors are willing to sacrifice some returns to hold green bonds. Tang and Zhang (2020) construct a comprehensive dataset that cover all corporate green bond issuance worldwide and find that issuers' stock prices increase significantly around the announcement of green bond issuance. They argue that green bond issuance is a proxy for firms to make environment-friendly investments and, thus is followed by positive market reactions. Similarly, Flammer (2021) documents a positive relation between green bond issuance and stock returns as well as financial performance, suggesting that green bonds are value-enhancing. Moreover, Flammer (2021) finds that the effect is significant only when certified green bonds are examined, which suggests that certification is a key governance mechanism for green bonds. The broader literature has also provided evidence on the positive impact of corporate social responsibility or environmental, social, and governance investment on firm performance or valuation (e.g., Sharfman and Fernando 2008; Hong and Kacperczyk 2009; Alex and Edmans 2011; Ghoul et al. 2011; Goss and Roberts 2011; Hong and Kostovetsky 2012; Flammer 2013; Servaes and Tamayo 2013; Chava 2014; Krueger 2015; Bhandari and Javakhadze 2017; Edmans, Li, and Zhang 2014).

Very few existing studies on green bonds have investigated their impact on environmental performance directly. Flammer (2021) was the first to have such attempts. Flammer (2021) document that, in addition to positive market reactions, the issuance of green bonds is also followed by improvements in environmental performance in terms of increased environmental ratings and reduced carbon dioxide emissions, which supports the signaling argument of green bond issuance. We join Flammer (2021) to directly examine the environmental outcomes of green bond issuance with a focus on air quality. If the issuance of green bonds credibly signals firms' intention to participate in environment- and sustainability-oriented activities, we would expect it to be followed by significant improvements in local air quality. The improvements may come from (i) firms' usage of the proceeds raised through green bond issuance for the promotion of environmental benefits, and (ii) firms' commitment to become environmentally responsible, which is revealed through their costly green bond issuance. These considerations lead to our first hypothesis as follows:

H1: The issuance of green bond is followed by significant improvements in local air quality, ceteris paribus.

B. Air Quality, Health Conditions, and Mortality Rates

Exposure to air pollution has serious health consequences. According to the 2020 Global Air report issued by the Health Effects Institute, air pollution is a leading risk factor that contributes to millions of deaths each year. The Health Effects Institute estimates that air pollution accounts for more than 1 in 9 deaths globally and contributed to 6.67 million deaths worldwide in 2019. Air pollution increases individuals' risk of illness and death from several major diseases, including ischemic heart disease, lung cancer, chronic obstructive pulmonary disease, lower respiratory infections (such as pneumonia), stroke, type 2 diabetes, and a range of neonatal diseases related primarily to low birth weight and preterm birth (State of Global Air 2020).

The negative impacts of air pollution on people's health as well as its association with mortality rates have been documented in the literature. Chay and Greenstone (2003) utilize the 1981–1982 recession period to examine the impact of air pollution on infant mortality, and document that a 1% reduction in total suspended particulates results in a 0.35% decline in infant mortality rate. Currie and Neidell (2005) examine the impact of air pollution on infant deaths in California over the 1990s and find similar conclusion: the reductions in carbon monoxide during the 1990s saved about 1,000 infant lives in California. A couple of studies examined the consequences of forest wildfires and show that the severe air pollution generated after the fires significantly impair local residents' health conditions, especially those of infants and the elderly, and in poor areas and regions where background levels of air pollution are low (e.g., Jayachandran 2009; Sheldon and Sankaran 2017; Miller, Molitor, and Zou 2017). He, Liu, and Zhou (2020) use satellite data to detect agricultural straw burnings and estimates their impact on air pollution and health in the PRC. They find that straw burning increases particulate matter pollution that causes people to die from cardio-respiratory diseases, and that a 10μg/m3 increase in $PM_{2.5}$ will increase mortality by 3.25%.

If air pollution significantly damages people's health and, thus, is positively associated with mortality rates, and if green bond issuance helps to reduce air pollution, we should expect green bond issuance to be followed by reduced mortality rates of local residents. We, therefore, propose our second hypothesis as follows:

H2: The issuance of green bond is followed by a significant reduction in local mortality rates, ceteris paribus.

III. SAMPLE CONSTRUCTION AND RESEARCH DESIGN

A. Data

The data used in this study are from multiple sources. Green bond information such as issuance size, issuer, issuance time, maturity, coupon type, and third-party verifier or certificate is collected from the Wind financial database. As green bond data started in 2015, these consist of 163 unique green bonds issued during 2015–2018.

Air quality information is collected from the China Meteorological Data Service Center, where daily information on AQI and its various contents of air pollution, including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O3), and particulate matters ($PM_{2.5}$ and PM_{10}), are available for 355 cities in the PRC during the period of 2015–2018. The AQI ranges from 0 to 500, with a higher AQI indicating greater pollution. Daily weather conditions, including wind speed, wind direction, relative humidity, precipitation, and temperature, were also collected from this data service center. We then average them by month and match them with monthly air quality data.

The province-level mortality rates during 2015–2019 are obtained from the China Stock Market & Accounting Research Database. Province-level GDP information is also collected from the China Stock Market & Accounting Research Database, while city-level GDP information is collected from the China City Statistical Yearbook.

The data are organized into a city–month panel data to investigate the causal relationship between green bond issuance and air quality. The sample consists of 5,344 observations, covering 265 cities during 2015–2018. To examine the link between green bond issuance and mortality, we formed province-year panel data because the mortality rate data are only available annually and city-level mortality information is not available prior to 2018. The province-year panel consists of 124 observations, covering 31 provinces in the PRC during 2015–2019. Summary statistics in Table 1 show that green bond issuance is relatively lower at city-month level when compared to province-year level because of 5,275 city-month observations with no green bond issuance.

Table 1: Summary Statistics

Variable	N	Mean	Median	SD	Pct 25	Pct 75
Panel A: City–Month Level						
Greenbond (%)	5344	0.686	0.000	0.074	0.000	0.000
Certified Greenbond (%)	5344	0.489	0.000	0.063	0.000	0.000
Uncertified Greenbond (%)	5344	0.197	0.000	0.039	0.000	0.000
AQI	5344	70.376	65.164	25.904	51.525	84.290
$PM_{2.5}$	5344	39.690	34.746	21.363	25.097	48.850
PM_{10}	5344	73.502	65.016	35.422	47.161	92.738
NO_2	5344	28.846	26.803	12.599	19.328	36.459
SO_2	5344	13.642	11.417	9.632	8.016	16.458
CO	5344	0.889	0.840	0.313	0.679	1.035
GDP Growth (%)	5344	8.755	7.580	0.219	4.641	9.890
Temperature	5344	2.808	2.982	0.602	2.561	3.243

continued on next page

Table 1 *continued*

Variable	N	Mean	Median	SD	Pct 25	Pct 75
Panel A: City–Month Level						
Humidity	5344	4.254	4.316	0.209	4.167	4.398
Wind Speed	5344	1.142	1.132	0.230	0.988	1.271
Rain	5344	1.192	1.174	0.697	0.652	1.691
Panel B: Province–Year Level						
Mortality Rate (%)	124	0.616	0.621	0.000	0.552	0.697
Greenbond (%)	124	3.713	0.000	0.074	0.000	4.201
Certified Greenbond (%)	124	2.455	0.000	0.049	0.000	2.311
Uncertified Greenbond (%)	124	1.258	0.000	0.048	0.000	0.134
GDP Growth (%)	124	7.712	8.668	0.078	6.053	10.931

AQI = air quality index, CO = carbon monoxide, GDP = gross domestic product, NO_2 = nitrogen dioxide, Pct = percentile, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide, SD = standard deviation.

Notes: Table 1 reports summary statistics of our sample. Panel A reports city–month observations' characteristics. Panel B reports province–year observations' characteristics. All variables are defined in Table A1.

Source: Authors' calculations.

B. Variable Construction

(1) Green Bond Issuance

To capture a city's participation in the green bond market, we define green bond issuance of a city ($Greenbond$) as the share of green bond issuance of city i in month t in its total bond issuance as shown below:

$$Greenbond_{i,t} = \frac{GBI_{i,t}}{BI_{i,t}}, \tag{1}$$

where $GBI_{i,t}$ is amount of green bond issuance of city i in month t, and $BI_{i,t}$ is the aggregated bond issuance of city i in month t.

Among green bonds, those issued with a third-party certification or review are documented to signal stronger environmental commitment and better environmental performance (Flammer 2019 and 2021), and are better received by investors to enjoy lower yields (Kapraun et al 2021; Hyun, Park, and Tian 2020). To better capture whether more green bond financing with a third party certification or review will lead to environmental consequences and health performance, we further split the green bond issuance into certified and uncertified green bond issuance, and examine their respective impact on air quality and mortality rates across cities. Specifically, for each city i, the certified and uncertified green bond issuance ratios are defined as the certified green bond issuance as a share of total bond issuance ($Certified\ Greenbond_{i,t}$) and uncertified green bond issuance as a share of total bond issuance ($Uncertified\ Greenbond_{i,t}$) in month t.

(2) Air Quality and Mortality Rates

To measure a city's air quality, we construct two sets of variables. The first measure is to gauge a city's air quality (AQ) using AQI and its components, which include levels of SO_2, NO_2, CO, O3, $PM_{2.5}$, and PM_{10}. To obtain the monthly air quality of a city, we use the arithmetic mean of daily air quality indexes and its components.

According to the Ministry of Environmental Protection of China, air pollution level is classified into seven categories: (i) excellent (air quality) when AQI is under 50, (ii) good for AQI between 50 and 100, (iii) slightly polluted for AQI between 101 and 150, (iv) lightly polluted for AQI between 151 and 200, (v) moderately polluted for AQI between 201 and 250, (vi) heavily polluted for AQI between 250 and 300, and (vii) severely polluted for AQI above 300.

Mortality rate is defined as the ratio of number of deaths to the average population in a province in a year.

C. Model Specification

To empirically examine whether a city's green bond issuance will improve air quality in the future, we estimate the following model specification:

$$\begin{aligned} AQ_{i,t+12} = \alpha &+ \beta_1 Greenbond_{i,t} + \beta_2 GDP\ Growth_{i,t} + \beta_3 Temperature_{i,t+12} \\ &+ \beta_4 Humidity_{i,t+12} + \beta_5 Wind\ Speed_{i,t+12} + \beta_6 Rain_{i,t+12} \\ &+ \beta_7 Wind\ Direction_{i,t+12} + \gamma C_i + \delta M_t + \varepsilon_{i,t+12}, \end{aligned} \tag{2}$$

where $AQ_{i,t+12}$ is the air quality index and its related subcomponents including AQI, $PM_{2.5}$, NO_2, PM_{10}, CO, and SO_2 for city i in month t+12. $Greenbond_{i,t}$ is a vector of green bond issuance variables, including total green bond issuance of city *i* as a share of total bond issuance of city *i* in month *t*, as well as the city *i*'s certified green bond issuance and uncertified green bonds issuance to total bond issuance in month *t*. $GDP\ Growth_{i,t}$ is the GDP growth rate for city i in the most recent year. $Temperature_{i,t+12}$, $Humidity_{i,t+12}$, $Wind\ Speed_{i,t+12}$, $Rain_{i,t+12}$ and $Wind\ Direction_{i,t+12}$, are the monthly weather conditions, i.e., temperature, relative humidity, wind speed, precipitation, and wind direction for city *i* in month t+12, and C_i is a vector of city fixed effects that capture each city's time-invariant attributes while M_t is a vector of month fixed effects to capture changes in overall conditions in each month. $\varepsilon_{i,t+12}$ is the error term.

In the above model specifications, the coefficient of interest is β_1, which is expected to be negative and significant if green bond helps to improve air quality and reduce air pollution levels. β_1 is also expected to be more pronounced for certified green bonds and in high–GDP-growth regions.

There is plenty of evidence showing the negative impact of air pollution on people's lungs, which pose health risks (Li, et.al, 2017). If green bond issuance can effectively reduce air pollution, it is therefore interesting to know whether green bond financing can deliver any health implications. To investigate the health effects of green bonds, we employ the following empirical model specifications.

$$Mortality_{i,t+1} = \alpha + \beta_1 Greenbond_{i,t} + \beta_2 GDP\ Growth_{i,t} + \gamma P_i + \delta Y_t + \varepsilon_{i,t+1}, \tag{3}$$

where $Mortality_{i,t+1}$ is the mortality rate for province *i* in year *t*, which is the ratio of number of deaths to average annual population. $Greenbond_{i,t}$ is the green bond issuance of province *i* as a share of total bond issuance in year *t*. Similarly, we also consider the ratio of certified green bond and uncertified green bond to total bond issuance of a province, respectively. $GDP\ Growth_{i,t}$ is GDP growth rate for province *i* in year *t*. P_i is a province fixed effect to account for time-invariant attributes, and Y_t is a year fixed effect to capture the changes in the overall economy. $\varepsilon_{i,t+1}$ is the error term. The coefficient of interest is β_1, which is expected to be negative and significant if green bond issuance can reduce mortality rate, and this effect is expected to be more pronounced for certified green bonds and in high–GDP-growth rate regions.

IV. EMPIRICAL RESULTS

A. Green Bond Financing and Local Air Quality

We expect that green bond financing is associated with improvements in local air quality, as stated in *H1*, either because the proceeds from the issuance are used for eco-friendly projects or because the issuance signals issuers' commitment to the environment, which materializes in their environmentally responsible behavior. We test this hypothesis using equation (2) specified in section III.C. The results are reported in Table 2.

Table 2: The Influence of Green Bond Issuance on Air Quality

Variables	(1) *AQI*	(2) *$PM_{2.5}$*	(3) *PM_{10}*	(4) *SO_2*	(5) *NO_2*	(6) *CO*
Greenbond	−5.530**	−4.389**	−4.608	−0.726	−0.418	−0.027
	(−2.47)	(−2.36)	(−1.57)	(−0.65)	(−0.47)	(−0.94)
GDP Growth	0.139	−0.377	−0.707	−0.410	−0.817**	−0.004
	(0.15)	(−0.48)	(−0.57)	(−0.87)	(−2.18)	(−0.33)
Temperature	−2.936***	−3.520***	−3.108***	−1.522***	−0.751***	−0.049***
	(−11.36)	(−16.43)	(−9.19)	(−11.82)	(−7.37)	(−14.91)
Humidity	−29.930***	−9.967***	−48.519***	−9.050***	−3.102***	0.023
	(−16.22)	(−6.51)	(−20.10)	(−9.84)	(−4.26)	(0.96)
Wind Speed	−6.976***	−7.841***	−12.655***	−3.625***	−10.835***	−0.136***
	(−5.55)	(−7.52)	(−7.70)	(−5.79)	(−21.86)	(−8.50)
Rain	−0.138	−0.407**	−0.575**	−0.377***	−0.231***	−0.007**
	(−0.68)	(−2.41)	(−2.16)	(−3.72)	(−2.88)	(−2.52)
Constant	199.861***	92.564***	290.217***	58.471***	53.851***	0.821***
	(22.38)	(12.50)	(24.84)	(13.15)	(15.30)	(7.22)
Observations	5,344	5,344	5,344	5,344	5,344	5,344
R-squared	0.813	0.811	0.829	0.664	0.877	0.792
Wind Direction	YES	YES	YES	YES	YES	YES
City and month FE	YES	YES	YES	YES	YES	YES

AQI = air quality index, CO = carbon monoxide, FE = fixed effects, GDP = gross domestic product, NO_2 = nitrogen dioxide, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide.

Notes: Table 2 examines the influence of green bond issuance on air quality. Columns (1)–(6) report the effects of green bond issuance on *AQI*, *$PM_{2.5}$*, *PM_{10}*, *SO_2*, *NO_2*, and *CO*, respectively. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. ** and *** represent statistical significance at 5% and 1% level, respectively.

Source: Authors' estimates.

In Table 2, we find that cities' environmental performance goes up substantially in 1 year following the issuance of green bonds. In particular, columns (1) and (2) show that 1 standard deviation higher green bond issuance as a share of total bond issuance is related to 0.58% and 0.82% decrease in AQI and $PM_{2.5}$, respectively (given the mean of 70.4 and 39.7 from Table 1), which means that the city with more frequent green bond issuance in a specific month will see a significantly lower AQI and $PM_{2.5}$ concentration after 12 months. These results indicate that cities improve their environmental performance following the issuance of green bonds, which is consistent with the signaling argument, as it suggests that corporate green bonds do signal subsequent improvements in environmental performance.

In Table 3, we revisit the results of Table 2 to examine the role of certification. Specifically, we define $Certified\ Greenbond_{i,t}$ and $Uncertified\ Greenbond_{i,t}$ as the green bond issuance certified and uncertified by independent third parties as a share of total bond issuance for city i in month t. As certified green bonds have stronger signaling effect (Flammer 2021), in columns (1)–(12), we break down green bond issuance into certified and uncertified green bond issuance to test whether cities issuing more certified green bonds witnessed better air quality. Consistent with Flammer (2021), results show that only certified green bonds are related to subsequent air quality, while the uncertified green bonds are insignificantly related to air quality. In column (1) and column (3), a 1 standard deviation higher certified green bond issuance as a share of total bond issuance is related to 0.523% and 0.611% decrease in AQI and $PM_{2.5}$, respectively (given the mean of 70.4 and 39.7 from Table 1). As columns (1) and (2) show, the estimates are large and significant for certified green bonds but small and insignificant for uncertified green bonds, which means that only certified green bonds contribute to the improvement of subsequent air quality or, in other words, the air quality effect of green bonds is largely driven by certified green bond issuance. These findings are again consistent with the signaling argument—certification is a costlier signal, and hence reflects a stronger commitment toward the natural environment.

B. High versus Low-Gross Domestic Product-Growth Regions

To investigate the environmental impact of green bonds in regions with significantly different economic attributes, we split the sample into two subsamples according to last year's GDP growth rate for each observation. More specifically, we get the median value of GDP growth rate for all cities in a year, and cities with a GDP growth rate higher (lower) than the median value will be assigned to the subsample with higher (lower) GDP growth rate in the next year. We conduct the specification test in equation (2) in these two subsamples, respectively. Columns (1)–(6) and (7)–(12) of Table 4 show the estimation results in high- and low-GDP-growth rate regions, respectively. In regions with high-GDP growth rates, green bond issuance still has a significantly positive effect on air quality as columns (1) and (2) in panel A show. More specifically, a 1 standard deviation higher green bond issuance as a share of total bond issuance is related to 0.725% and 1.05% decrease in AQI and $PM_{2.5}$ (given the mean of 70.4 and 39.7 from Table 1). Combining the results in columns (7) and (8), the estimates are large and significant for green bonds in high-GDP-growth regions, while they are small and insignificant in low-GDP-growth regions.

C. Difference Test

To account for potential endogeneity, we conduct the difference test, i.e., regress change in air quality measures on change in green bonds:

Table 3: The Influence of Certified and Uncertified Green Bond Issuance on Air Quality

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Variables	***AQI***	***AQI***	***$PM_{2.5}$***	***$PM_{2.5}$***	***PM_{10}***	***PM_{10}***	***SO_2***	***SO_2***	***NO_2***	***NO_2***	***CO***	***CO***
Certified Greenbond	−5.873**		−3.840*		−4.067		−0.915		0.251		−0.027	
	(−2.23)		(−1.76)		(−1.18)		(−0.70)		(0.24)		(−0.80)	
Uncertified Greenbond		−4.473		−5.651		−5.845		−0.220		−2.115		−0.026
		(−1.06)		(−1.62)		(−1.06)		(−0.10)		(−1.28)		(−0.49)
GDP Growth	0.140	0.141	−0.377	−0.377	−0.706	−0.706	−0.410	−0.410	−0.817**	−0.817**	−0.004	−0.004
	(0.15)	(0.15)	(−0.48)	(−0.48)	(−0.57)	(−0.57)	(−0.87)	(−0.86)	(−2.18)	(−2.18)	(−0.33)	(−0.33)
Temperature	−2.939***	−2.937***	−3.522***	−3.519***	−3.110***	−3.107***	−1.522***	−1.522***	−0.751***	−0.750***	−0.049***	−0.049***
	(−11.37)	(−11.36)	(−16.44)	(−16.42)	(−9.20)	(−9.19)	(−11.83)	(−11.82)	(−7.38)	(−7.37)	(−14.91)	(−14.91)
Humidity	−29.908***	−29.883***	−9.944***	−9.939***	−48.495***	−48.489***	−9.048***	−9.042***	−3.095***	−3.106***	0.023	0.023
	(−16.20)	(−16.18)	(−6.50)	(−6.49)	(−20.09)	(−20.08)	(−9.84)	(−9.84)	(−4.25)	(−4.27)	(0.97)	(0.97)
Wind Speed	−6.985***	−6.973***	−7.848***	−7.835***	−12.663***	−12.649***	−3.627***	−3.625***	−10.835***	−10.832***	−0.136***	−0.136***
	(−5.56)	(−5.54)	(−7.53)	(−7.52)	(−7.70)	(−7.69)	(−5.79)	(−5.79)	(−21.86)	(−21.86)	(−8.50)	(−8.49)
Rain	−0.142	−0.138	−0.411**	−0.406**	−0.579**	−0.573**	−0.378***	−0.378***	−0.231***	−0.230***	−0.007**	−0.007**
	(−0.70)	(−0.68)	(−2.43)	(−2.40)	(−2.17)	(−2.15)	(−3.73)	(−3.72)	(−2.88)	(−2.86)	(−2.53)	(−2.51)
Constant	199.793***	199.662***	92.483***	92.436***	290.133***	290.082***	58.467***	58.440***	53.823***	53.861***	0.821***	0.820***
	(22.37)	(22.35)	(12.49)	(12.48)	(24.83)	(24.83)	(13.14)	(13.14)	(15.29)	(15.30)	(7.22)	(7.21)
Observations	5,344	5,344	5,344	5,344	5,344	5,344	5,344	5,344	5,344	5,344	5,344	5,344
R-squared	0.813	0.813	0.811	0.811	0.829	0.829	0.664	0.664	0.877	0.877	0.792	0.792
Wind Direction	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
City and month FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

AQI = air quality index, CO = carbon monoxide, FE = fixed effects, GDP = gross domestic product, NO_2 = nitrogen dioxide, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide.

Notes: Table 3 compares the influence of certified and uncertified green bond issuance on air quality. Columns (1), (3), (5), (7), (9), and (11) report the effects of certified green bond issuance on AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO, respectively. Columns (2), (4), (6), (8), (10), and (12) report the effects of uncertified green bond issuance on AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO, respectively. All variables are defined in Table A1. The t-statistics are reported in parentheses. *, **, and *** represent statistical significance at 10%, 5%, and 1% level, respectively.

Source: Authors' estimates.

Table 4: The Influence of Green Bond Issuance on Air Quality in High- and Low-Gross Domestic Product-Growth Regions

	Panel A: High-GDP-Growth Regions						Panel B: Low-GDP-Growth Regions					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Variables	***AQI***	***$PM_{2.5}$***	***PM_{10}***	***SO_2***	***NO_2***	***CO***	***AQI***	***PM2.5***	***PM_{10}***	***SO_2***	***NO_2***	***CO***
Greenbond	−6.894**	−5.622**	−5.964	0.156	−0.627	−0.021	−0.431	−0.047	−0.323	−1.319	1.278	−0.011
	(−2.41)	(−2.41)	(−1.64)	−0.18	(−0.54)	(−0.63)	(−0.12)	(−0.02)	(−0.07)	(−0.59)	(−0.94)	(−0.23)
GDP Growth	−0.213	−0.037	−0.606	1.894***	0.815	0.001	−1.814	−4.278	−6.518	−4.401*	−6.238***	−0.046
	(−0.12)	(−0.03)	(−0.27)	−3.55	−1.14	−0.07	(−0.48)	(−1.37)	(−1.28)	(−1.84)	(−4.34)	(−0.91)
Temperature	−10.039***	−11.242***	−10.936***	−2.952***	−2.582***	−0.124***	−1.845***	−2.248***	−1.741***	−1.129***	−0.410***	−0.036***
	(−14.88)	(−20.42)	(−12.73)	(−14.38)	(−9.38)	(−15.72)	(−6.47)	(−9.58)	(−4.53)	(−6.26)	(−3.78)	(−9.38)
Humidity	−34.122***	−12.774***	−51.296***	−7.852***	−5.643***	0.017	−27.418***	−7.850***	−47.385***	−9.397***	−2.215**	0.012
	(−12.53)	(−5.75)	(−14.79)	(−9.48)	(−5.08)	−0.52	(−10.63)	(−3.70)	(−13.62)	(−5.76)	(−2.26)	−0.34
Wind Speed	−7.936***	−7.117***	−13.170***	−1.710***	−12.252***	−0.120***	−6.102***	−7.946***	−13.573***	−5.323***	−10.396***	−0.136***
	(−4.48)	(−4.93)	(−5.84)	(−3.17)	(−16.96)	(−5.79)	(−3.34)	(−5.28)	(−5.50)	(−4.60)	(−14.94)	(−5.55)
Rain	−0.183	−0.437*	−1.020***	−0.220***	−0.252**	−0.011***	−0.29	−0.571**	−0.295	−0.491***	−0.270**	−0.002
	(−0.67)	(−1.94)	(−2.91)	(−2.62)	(−2.24)	(−3.38)	(−0.97)	(−2.32)	(−0.73)	(−2.59)	(−2.37)	(−0.51)
Constant	219.112***	112.111***	307.345***	50.442***	63.477***	1.058***	184.721***	80.407***	280.675***	61.421***	49.336***	0.868***
	(15.43)	(9.68)	(16.99)	(11.67)	(10.96)	(6.38)	(15.18)	(8.02)	(17.1)	(7.98)	(10.66)	(5.33)
Observations	2,797	2,797	2,797	2,797	2,797	2,797	2,558	2,558	2,558	2,558	2,558	2,558
R-squared	0.823	0.828	0.836	0.781	0.887	0.79	0.827	0.829	0.841	0.645	0.885	0.825
Wind Direction	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
City and month FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

AQI = air quality index, CO = carbon monoxide, FE = fixed effects, GDP = gross domestic product, NO_2 = nitrogen dioxide, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide.

Notes: Table 4 examines the influence of green bond issuance on air quality in high/low-GDP-growth regions. Panel A (B) reports the estimation results in the subsample of high- (low-) GDP-growth regions. Columns (1)–(6) report the effects of green bond issuance on *AQI*, *$PM_{2.5}$*, *PM_{10}*, *SO_2*, *NO_2*, and CO, respectively in high-GDP-growth regions. Columns (7)–(12) report the effect of green bond issuance on *AQI*, *$PM_{2.5}$*, *PM_{10}*, *SO_2*, *NO_2*, and CO, respectively in low-GDP-growth regions. The low and high groups are partitioned based on the median of the GDP growth rates: we get the median value of the GDP growth rates for all cities in a year, and cities with GDP growth rates that are higher (lower) than the median value is assigned to the subsample with higher (lower) GDP growth rate in the next year. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. *, **, and *** represent statistical significance at 10%, 5%, and 1% level, respectively.

Source: Authors' estimates.

$$\Delta AQ_{i,t+12} = \alpha + \beta_1 \Delta Greenbond_{i,t} + \beta_2 GDP\ Growth_{i,t} + \beta_3 Temperature_{i,t+12} \\ +\beta_4 Humidity_{i,t+12} + \beta_5 Wind\ Speed_{i,t+12} + \beta_6 Rain_{i,t+12} + \beta_7 Wind\ Direction_{i,t+12} \\ +\gamma C_i + \delta M_t + \varepsilon_{i,t+12}, \quad (4)$$

where i indexes cities, t indexes months; $\alpha$is the intercept; $AQ$is the outcome variable of interest including AQI, $PM_{2.5}$, NO_2, PM_{10}, CO, and SO_2; $\Delta AQ_{i,t+12} = AQ_{i,t+12} - AQ_{i,t}$;$Greenbond_{i,t}$ is as previously defined; $\Delta Greenbond_{i,t+12} = Greenbond_{i,t} - Greenbond_{i,t-12}$; $GDP\ Growth_{i,t}$ is GDP growth rate for city i in the most recent year. $Temperature_{i,t+12}$, $Humidity_{i,t+12}$, $Wind\ Speed_{i,t+12}$, $Rain_{i,t+12}$ and $Wind\ Direction_{i,t+12}$, are the monthly weather conditions, temperature, relative humidity, wind speed, precipitation, and wind direction for city *i* in month *t+12* respectively, and C_i is a vector of city fixed effects that captures each city's time-invariant attributes while M_t is a vector of month fixed effect to capture changes in overall conditions in each month. $\varepsilon_{i,t+12}$ is the error term. The coefficient of interest is β_1, which measures the change in AQ difference for a 1 unit change in $Greenbond$ difference and we still expect a negative coefficient on green bond and (i.e., β_1<0). The estimated results are shown in Table 5. We get a robust relationship between green bond and air quality in this difference test. More specifically, in columns (1) and (2), β_1 is negative and significant, which is consistent to our conjecture.

Table 5: Robustness Test—Using Difference

Variables	(1) Δ *AQI*	(2) Δ *PM2.5*	(3) Δ *PM10*	(4) Δ *SO2*	(5) Δ *NO2*	(6) Δ *CO*
Δ *Greenbond*	–5.145**	–3.536*	–5.374	–0.387	–0.305	–0.028
	(–2.06)	(–1.76)	(–1.54)	(–0.45)	(–0.33)	(–0.91)
Temperature	–1.284***	–1.075***	–0.340	0.584***	–0.186	0.006
	(–4.04)	(–4.20)	(–0.77)	(5.28)	(–1.56)	(1.60)
Humidity	–31.712***	–15.702***	–44.828***	–2.433**	–9.953***	–0.039
	(–10.94)	(–6.72)	(–11.08)	(–2.41)	(–9.14)	(–1.09)
Wind Speed	–8.446***	–6.926***	–18.428***	–3.729***	–8.660***	–0.067***
	(–4.19)	(–4.26)	(–6.54)	(–5.31)	(–11.43)	(–2.70)
Rain	–0.620*	–0.290	–1.463***	–0.319***	–0.378***	0.004
	(–1.84)	(–1.07)	(–3.12)	(–2.73)	(–2.99)	(1.03)
Constant	154.821***	78.498***	220.906***	13.598***	56.263***	0.209
	(11.30)	(7.11)	(11.55)	(2.85)	(10.93)	(1.24)
Observations	2,607	2,607	2,607	2,607	2,607	2,607
R-squared	0.393	0.320	0.400	0.480	0.455	0.391
Wind Direction	YES	YES	YES	YES	YES	YES
City and month FE	YES	YES	YES	YES	YES	YES

AQI = air quality index, CO = carbon monoxide, FE = fixed effects, NO2 = nitrogen dioxide, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide.

Notes: In Table 5, we conduct the difference-in-differences test shown in equation (4) to regress change in air quality measures on lagged change of *Greenbond*. Columns (1)–(6) report the effect of change in *Greenbond* on change in AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO, respectively. All variables are defined in Table A1. The t-statistics are reported in parentheses. *, **, and *** represent statistical significance at 10%, 5%, and 1% level, respectively.

Source: Authors' estimates.

D. Reverse Causality

We may conclude that the city with more frequent green bond issuance in a specific month will see a significantly lower AQI and $PM_{2.5}$ concentration after 12 months according to the previous estimation results. However, will air quality especially for AQI and $PM_{2.5}$ itself affect city-level green bond issuance? To address potential reverse causality concern, we conduct the reverse change test where the dependent variable is the change in green bond issuance and the independent variable is the change in air quality:

$$\Delta Greenbond_{i,t+12} = \alpha + \beta_1 \Delta AQ_{i,t} + \gamma C_i + \delta M_t + \varepsilon_{i,t+12}, \quad (5)$$

where i indexes cities, t indexes months; $\Delta AQ_{i,t} = AQ_{i,t} - AQ_{i,t-12}$; $\Delta Greenbond_{i,t+12} = Greenbond_{i,t+12} - Greenbond_{i,t}$; C_i is a vector of city fixed effects that captures each city's time-invariant attributes while M_t is a vector of month fixed effects to capture changes in overall conditions in each month. $\varepsilon_{i,t+12}$ is the error term. The coefficient of interest is β_1, which measures the change in $Greenbond$ difference for 1 unit change in AQ difference and we expect a nonsignificant coefficient on $\Delta AQ_{i,t}$ because we assume that green bond issuance is not driven by air pollution. The estimation results are shown in Table 6. The coefficient on $\Delta AQ_{i,t}$ is nonsignificant in columns (1)–(5) as expected, which indicates that there is no significant relationship between the change in AQI and $PM_{2.5}$ concentration and the change in green bond issuance while we get a significantly positive β_1 in column (6). This also implies that our findings on the environmental impact of green bond are unlikely to be driven by reverse causality.

Table 6: Robustness Test—Reverse Causality

	(1)	(2)	(3)	(4)	(5)	(6)
Variables			***Δ Greenbond***			
Δ AQI	0.000 (0.92)					
Δ $PM_{2.5}$		0.000 (0.82)				
Δ PM_{10}			0.000 (0.99)			
Δ SO_2				0.000 (1.05)		
Δ NO_2					0.000 (0.16)	
Δ CO						0.008* (1.70)
Constant	−0.005 (−0.20)	−0.005 (−0.20)	−0.005 (−0.21)	−0.005 (−0.19)	−0.006 (−0.23)	−0.005 (−0.19)
Observations	7,419	7,419	7,419	7,419	7,419	7,419
R-squared	0.027	0.027	0.027	0.027	0.027	0.028
City and month FE	YES	YES	YES	YES	YES	YES

AQI = air quality index, CO = carbon monoxide, FE = fixed effects, NO_2 = nitrogen dioxide, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide.

Note: In Table 6, we conduct the reverse change test shown in equation (5) to regress change in *Greenbond* on lagged change in air quality measures. Columns (1)–(6) report the effect of change of lagged *AQI*, *$PM_{2.5}$*, *PM_{10}*, *SO_2*, *NO_2*, and *CO* on change of *Greenbond,* respectively. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. * represents statistical significance at 10% level.

Source: Authors' estimates.

E. Generalized Method of Moments Test

We then relax the assumption of strict exogeneity in the fixed effects model as in equation (2) and estimate the dynamic one step Generalized Method of Moments (GMM) model developed by Arellano and Bond (1991), in which $Greenbond$ is assumed to be endogenous and instrumented with 1-month lagged value of $Greenbond$ in levels. This method allows us to control for persistence in the air quality measures and time-invariant city characteristics. The estimation results are shown in Table 7. As shown in columns (1) and (2), we get a robust relationship between AQI or $PM_{2.5}$ and lagged green bond issuance. Further, we can conclude that green bond issuance has significant and negative effects on PM_{10}, and SO_2 in addition to AQI and $PM_{2.5}$. It is notable that the effects on PM_{10}, and SO_2 are even not significant in Table 2. Overall, after controlling for persistence in the air quality measures and time-invariant city characteristics, the estimation results in Table 7 are supportive of our conjecture that the environmental impact of green bond issuance is strong and robust.

Table 7: Robustness Test—One-Step System Generalized Method of Moments

Variables	(1) *AQI*	(2) *$PM_{2.5}$*	(3) *PM_{10}*	(4) *SO_2*	(5) *NO_2*	(6) *CO*
Greenbond	−12.928**	−7.013*	−18.307**	−2.803*	−3.197	−0.105
	(−2.30)	(−1.82)	(−1.99)	(−1.93)	(−1.19)	(−1.55)
GDP Growth	54.169	57.187*	49.249	−2.535	21.096	−0.065
	(1.32)	(1.67)	(1.09)	(−0.22)	(0.85)	(−0.10)
Temperature	−25.093***	−21.810***	−22.373***	−3.668***	−10.869**	−0.246***
	(−2.74)	(−2.78)	(−2.90)	(−2.79)	(−2.47)	(−2.63)
Humidity	−38.161	−11.533	−56.876**	2.616	−20.098*	−0.373
	(−1.53)	(−0.56)	(−2.40)	(0.53)	(−1.66)	(−1.31)
Wind Speed	−8.521	−10.362**	−17.361**	−1.078	3.545	−0.433***
	(−1.39)	(−2.00)	(−2.16)	(−0.41)	(0.66)	(−3.42)
Rain	−0.547	−0.482	−1.468	−0.742**	1.382	−0.002
	(−0.49)	(−0.52)	(−0.87)	(−2.29)	(1.53)	(−0.11)
Observations	5,344	5,344	5,344	5,344	5,344	5,344
Number of City	265	265	265	265	265	265
Wind Direction	YES	YES	YES	YES	YES	YES
Month Dummy	YES	YES	YES	YES	YES	YES
AR(1)	0.116	0.164	0.0204	0.0341	0.110	0.173
AR(2)	0.643	0.709	0.578	0.0224	0.525	0.232
Hansen Test	1	1	1	1	1	1
Sargan Test	1	1	1	1	1	1

AR = first or second order autocorrelation in the differenced residuals, and the null hypothesis is no first- or second-order autocorrelation in the differenced residuals. AQI = air quality index, CO = carbon monoxide, GDP = gross domestic product, NO_2 = nitrogen dioxide, PM_{10} = inhalable particles with particle size less than 10 microns, $PM_{2.5}$ = inhalable particles with particle size less than 2.5 microns, SO_2 = sulfur dioxide.

Notes: In Table 7, we estimate the dynamic one-step Generalized Method of Moments (GMM) model developed by Arellano and Bond (1991) in which *Greenbond is* assumed to be endogenous and instrumented with 1-month lagged value of *Greenbond* in levels. Columns (1)–(6) report the effect of green bond issuance on *AQI*, *$PM_{2.5}$*, *PM_{10}*, *SO_2*, *NO_2*, and *CO*, respectively using one-step system GMM model. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. *, **, and *** represent statistical significance at 10%, 5%, and 1% level, respectively.

Source: Authors' estimates.

To ensure the robustness of our findings, we further apply the total market value of listed firms scaled by GDP (Market Value) as additional instrumental variable and repeat the one-step GMM test. The results in Table 8 are qualitatively similar to our previous findings. The first two columns of Table 8 indicate that a 1 standard deviation increase in green bond issuance as a share of total bond finance is associated with declines of 1.359% and 1.113% in AQI and $PM_{2.5}$, respectively. The tests for second order autocorrelation in the differenced residuals support the assumption of the specification that the residuals in the levels equation are serially uncorrelated. From the p-values of the Sargan test of over-identifying restrictions, we note that we cannot reject the null hypothesis that the instruments are valid (p-values are 1). Overall, the estimation results in Table 7 and Table 8 are supportive of our conjecture that the positive environmental impact of green bond issuance is strong and robust.

Table 8: Robustness Test—One-Step System Generalized Method of Moments Using Instrument Variable

Variables	(1) *AQI*	(2) *$PM_{2.5}$*	(3) *PM_{10}*	(4) *SO_2*	(5) *NO_2*	(6) *CO*
Greenbond	−12.928**	−7.013*	−18.307**	−2.803*	−3.197	−0.105
	(−2.30)	(−1.82)	(−1.99)	(−1.93)	(−1.19)	(−1.55)
GDP Growth	54.169	57.187*	49.249	−2.535	21.096	−0.065
	(1.32)	(1.67)	(1.09)	(−0.22)	(0.85)	(−0.10)
Temperature	−25.093***	−21.810***	−22.373***	−3.668***	−10.869**	−0.246***
	(−2.74)	(−2.78)	(−2.90)	(−2.79)	(−2.47)	(−2.63)
Humidity	−38.161	−11.533	−56.876**	2.616	−20.098*	−0.373
	(−1.53)	(−0.56)	(−2.40)	(0.53)	(−1.66)	(−1.31)
Wind Speed	−8.521	−10.362**	−17.361**	−1.078	3.545	−0.433***
	(−1.39)	(−2.00)	(−2.16)	(−0.41)	(0.66)	(−3.42)
Rain	−0.547	−0.482	−1.468	−0.742**	1.382	−0.002
	(−0.49)	(−0.52)	(−0.87)	(−2.29)	(1.53)	(−0.11)
Observations	5,344	5,344	5,344	5,344	5,344	5,344
Number of cities	265	265	265	265	265	265
Wind Direction	YES	YES	YES	YES	YES	YES
Month FE	YES	YES	YES	YES	YES	YES
AR(1)	0.888	0.606	0.233	0.873	0.980	0.464
AR(2)	0.768	0.604	0.507	0.219	0.563	0.278
Hansen Test	1	1	1	1	1	1
Sargan Test	1	1	1	1	1	1

AR = first or second order autocorrelation in the differenced residuals, and the null hypothesis is no first or second order autocorrelation in the differenced residuals. AQI = air quality index, CO = carbon monoxide, GDP = gross domestic product, NO_2 = nitrogen dioxide, PM_{10} = inhalable particles with particle size less than 10 microns, $PM_{2.5}$ = inhalable particles with particle size less than 2.5 microns, SO_2 = sulfur dioxide.

Notes: In Table 8, we estimate the dynamic one-step Generalized Method of Moments (GMM) model developed by Arellano and Bond (1991), using *Market Value* as an additional instrumental variable, and in which *Greenbond* is assumed to be endogenous and instrumented with 1-month lagged value of *Greenbond* in levels. Columns (1)–(6) report the effects of green bond issuance on *AQI*, *$PM_{2.5}$*, *PM_{10}*, *SO_2*, *NO_2*, and *CO*, respectively, using one-step system GMM model. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. *, **, and *** represent statistical significance at 10%, 5%, and 1% level, respectively.

Source: Authors' estimates.

V. THE HEALTH IMPACT OF GREEN BOND SIGNALING

The relationships between green bond issuance and mortality rate are reported in Table 9. The first three columns report the relationship between green bond issuance and mortality rate where the GDP growth rate is not considered, while the last three columns show results where the GDP growth rate is considered. Columns (1) and (2) regress mortality rate on green bond issuance and certified green bond issuance, respectively. We find that a 1 standard deviation higher green bond finance as a share of total bond finance is related to a 0.028% decrease in mortality rate, and that a 1 standard deviation higher certified green bond finance as a share of total bond finance is related to a 0.025% decrease in mortality rate after controlling for the province and year fixed effects. The result shown in column (3) implies that uncertified green bond issuance does not contribute to a decrease in local residential mortality rate, in contrast to the results shown in columns (1) and (2). When GDP growth rate is added to the regression, we still get robust results that green bond issuance contributes to a decrease in local residential mortality rate, which is largely driven by certified green bond issuance just as columns (4)–(6) show.

Table 9: The Influence of Green Bond Issuance on Mortality

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Greenbond	−3.725***			−3.807***		
	(−2.90)			(−2.96)		
Certified Greenbond		−5.083**			−5.514***	
		(−2.62)			(−2.81)	
Uncertified Greenbond			−3.261			−3.171
			(−1.65)			(−1.59)
GDP Growth				−1.248	−1.662	−0.810
				(−0.94)	(−1.22)	(−0.59)
Constant	6.071***	6.123***	5.970***	6.210***	6.317***	6.059***
	(13.54)	(13.49)	(12.95)	(13.14)	(13.17)	(12.44)
Observations	124	124	124	124	124	124
R-squared	0.512	0.504	0.481	0.517	0.512	0.483
Province and year FE	YES	YES	YES	YES	YES	YES

FE = fixed effects, GDP = gross domestic product.

Note: Table 9 examines the relationship between green bond issuance and mortality rate. Columns (1)–(3) report the relationship between green bond issuance and mortality rate where GDP growth rate is not considered, while columns (4)–(6) shows the results where the GDP growth rate is considered. Columns (1) and (4), (2) and (5), and (3) and (6) regress mortality rate on green bond issuance, certified green bond issuance, and uncertified green bond issuance, respectively. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. ** and *** represent statistical significance at 5% and 1% level, respectively.

Source: Authors' estimates.

Similar to section IV.B., we split the sample into two subsamples according to last year's GDP growth rate for each observation to investigate the health impact of green bond issuance in regions with significantly different economic attributes. We conduct the specification test in equation (3) in these two subsamples, respectively. Columns (1)–(2) and (3)–(4) in Table 10 show estimation results in high- and low-GDP-growth regions, respectively. In regions with high-GDP growth rates, green bond issuance still has a significantly negative effect on mortality rate as columns (1)–(2) show. Combining the results in columns (3)–(4), the estimates are significant for green bonds in high-GDP-growth regions, while they are insignificant in low-GDP-growth regions, which is consistent with the results in Table 4.

Table 10: The Influence of Green Bond Issuance on Mortality in High- and Low-Gross Domestic Product-Growth Regions

	(1)	(2)	(3)	(4)
	High-GDP Growth		Low-GDP Growth	
Variables	*Mortality*	*Mortality*	*Mortality*	*Mortality*
Greenbond	−0.850***	−0.879***	−4.208	−4.206
	(−2.82)	(−2.99)	(−1.58)	(−1.55)
GDP Growth		−0.999		−0.310
		(−1.53)		(−0.13)
Constant	5.191***	5.313***	6.591***	6.600***
	(59.92)	(45.76)	(7.05)	(6.93)
Observations	58	58	66	66
R-squared	0.991	0.991	0.613	0.613
Province and year FE	YES	YES	YES	YES

FE = fixed effects, GDP = gross domestic product.

Note: Table 10 examines the influence of green bond issuance on mortality rate in high/low-GDP-growth regions. Columns (1)–(2) and columns (3)–(4) report the estimation results in the subsample of high- and low-GDP-growth regions, respectively. The low and high groups are partitioned based on the median of the GDP growth rates: we get median value of the GDP growth rates for all provinces in a year, and provinces with GDP growth rates that are higher (lower) than the median value are assigned to the subsample with higher (lower) GDP growth rate in the next year. All variables are defined in Table A1. The *t*-statistics are reported in parentheses. *** represents statistical significance at 1% level.

Source: Authors' estimates.

VI. CONCLUSION

In this study, we find that green bond issuance significantly improves local air quality, which is measured by AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO. We further show that green bond issuance contributes to a decrease in local residential mortality rate. In addition, the environmental and health impacts of green bond issuance are more evident when certified green bond issuance is considered and when issued in high-GDP-growth regions. We perform a series of robustness tests to address concerns over potential endogeneity, including change and reverse change regressions and GMM test to show the robust and strong effect of green bond issuance on air quality.

APPENDIX

Table A1: Variable Definitions

Green bond issuance measure	
Greenbond	The share of green bond issuance in total bond issuance.
Certified Greenbond	The share of green bond issuance certified by an independent third party in total bond issuance.
Uncertified Greenbond	The share of green bond issuance uncertified by an independent third party in total bond issuance.
Air quality index (*AQI*) and its subcomponents	
AQI	Average daily air quality index in month *t;* it refers to air pollution level, classified into seven categories according to the Ministry of Ecology and Environment of the PRC: (i) excellent (air quality) when *AQI* is under 50, (ii) good for *AQI* between 50 and 100, (iii) slightly polluted for *AQI* between 101 and 150, (iv) lightly polluted for *AQI* between 151 and 200, (v) moderately polluted for *AQI* between 201 and 250, (vi) heavily polluted for *AQI* between 250 and 300, and (vii) severely polluted for *AQI* above 300.
$PM_{2.5}$	Average daily $PM_{2.5}$ concentration in month *t*.
PM_{10}	Average daily PM_{10} concentration in month *t*.
SO_2	Average daily SO_2 concentration in month *t*.
NO_2	Average daily NO_2 concentration in month *t*.
CO	Average daily CO concentration in month *t*.
Control variables: Weather conditions and GDP growth rate	
Temperature	Average daily temperature in month *t*.
Humidity	Average daily relatively humidity in month *t*.
Wind Speed	Average daily wind speed in month *t*.
Rain	Average daily precipitation in month *t*.
Wind Direction	Average daily wind direction in month *t*. It is calculated based on daily wind directions and wind speed using vector decomposition (He, Liu, and Zhou 2020).
GDP Growth	The difference of GDP in year *t* and *t-1*, scaled by GDP in year *t-1*.
Province-level dependent variable	
Mortality Rate	The ratio of number of deaths to average annual population
Instrumental variable	
Market Value	Total market value of listed firms scaled by GDP in month *t*.

CO = carbon monoxide, GDP = gross domestic product, NO_2 = nitrogen dioxide, PM_{10} = particulate matter 10 (inhalable particles with particle size less than 10 microns), $PM_{2.5}$ = particulate matter 2.5 (inhalable particles with particle size less than 2.5 microns), SO_2 = sulfur dioxide, *t* = time.

Source: Authors' compilation.

REFERENCES

Alex, Edmans. 2011. "Does the Stock Market Fully Value Intangibles? Employee Satisfaction and Equity Prices." *Journal of Financial Economics* 101(3): 621–640.

Baker, Malcolm, Daniel Bergstresser, George Serafeim, and Jeffrey Wurgler. 2018. "Financing the Response to Climate Change: The Pricing and Ownership of U.S. Green Bonds." NBER Working Paper 25194, National Bureau of Economic Research, Cambridge, MA.

Berrone, Pascual, Andrea Fosfuri, and Liliana Gelabert. 2017. "Does Greenwashing Pay Off? Understanding the Relationship between Environmental Actions and Environmental Legitimacy." *Journal of Business Ethics* 144: 363–379.

Bhandari, Avishek, and David Javakhadze. 2017. "Corporate Social Responsibility and Capital Allocation Efficiency." *Journal of Corporate Finance* 43: 354-377

Chay, Kenneth Y., and Michael Greenstone. 2003. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession." *The Quarterly Journal of Economics* 118(3): 1121–1167.

Chava, Sudheer. 2014. "Environmental Externalities and Cost of Capital." *Management Science* 60(9): 2223–2247.

Currie, Janet, and Matthew Neidell. 2005. "Air Pollution and Infant Health: What Can We Learn from California's Recent Experience?" *Quarterly Journal of Economics* 120(3): 1003–1030.

Edmans, Alex, Lucius Li, and Chendi Zhang. 2014. "Employee Satisfaction, Labor Market Flexibility, and Stock Returns around the World." NBER Working Paper 20300, National Bureau of Economic Research, Cambridge, MA.

Ehlers Torsten, Benoit Mojon, and Frank Packer. 2020. "Green Bonds and Carbon Emissions: Exploring the Case for a Rating System at the Firm Level." BIS Quarterly Review (September). Bank for International Settlements, Basel, Switzerland.

Flammer, Caroline. 2013. "Corporate Social Responsibility and Shareholder Reaction: The Environmental Awareness of Investors." *Academy of Management Journal* 56 (3): 758–781.

———. 2015. "Does Corporate Social Responsibility Lead to Superior Financial Performance? A Regression Discontinuity Approach." *Management Science* 61 (11): 2549–2568.

———. 2019. "Green Bonds: Effectiveness and Implications for Public Policy." NBER Working Paper 25950, National Bureau of Economic Research, Cambridge, MA.

———. 2021. "Corporate green bonds." *Journal of Financial Economics (January)*. https://doi.org/10.1016/j.jfineco.2021.01.010.

Ghoul, Sadok E., Omrane Guedhami, Chuck C.Y. Kwok, and Dev R. Mishra,. 2011. "Does Corporate Social Responsibility Affect the Cost of Capital?." *Journal of Banking & Finance* 35 (9): 2388–2406.

Goss Allen, and Gordon S. Roberts. 2011. "The Impact of Corporate Social Responsibility on the Cost of Bank Loans." *Journal of Banking & Finance* 35 (7):1794–1810.

He, Guojun, Tong Liu, and Maigeng Zhou. 2020. "Straw Burning, $PM_{2.5}$ and Death: Evidence from China." *Journal of Development Economics* 145, 102468.

Health Effects Institute. 2020. *State of Global Air 2020*. Special Report. Boston, MA: Health Effects Institute.

Hong, Harrison, and Marcin Kacperczyk. 2009."The Price of Sin: The Effects of Social Norms on Markets." *Journal of Financial Economics* 93 (1): 15-36

Hong, Harrison, and Leonard Kostovetsky. 2012. "Red and Blue Investing: Values and Finance." *Journal of Financial Economics* 103(1): 1-19

Hyun, Suk, Donghyun Park, and Shu Tian. 2020. "The Price of Going Green: The Role of Greenness in Green Bond Markets." *Accounting & Finance* 60 (1): 73–95.

Jayachandran, Seema. 2009. "Air Quality and Early-life Mortality Evidence from Indonesia's Wildfires." *The Journal of Human Resources* 44(4): 916–954.

Kapraun, Julia, Carmelo Latino, Christopher Scheins, and Christian Schlag. 2021. "(In)-Credibly Green: Which Bonds Trade at a Green Bond Premium?" Proceedings of Paris December 2019 Finance Meeting EUROFIDAI – ESSEC. SSRN: https://ssrn.com/abstract=3347337.

Krueger, Philipp. 2015. "Corporate Goodness and Shareholder Wealth." *Journal of Financial Economics* 115: 304–329.

Klassen, Robert D., and Curtis P. McLaughlin. 1996. "The Impact of Environmental Management on Firm Performance." *Management Science* 42 (8): 1199–1214.

Li, Jennifer, Massimo Massa, Hong Zhang, and Jian Zhang. 2017. "Behavioral Bias in Haze: Evidence from Air Pollution and the Disposition Effect in China." *SSRN Electronic Journal*. http://52.76.234.106/media/abfer-events-2017/annual-conference/investment-finance/ac2017p3063_
behavioral_bias_in_haze.pdf.

Lyon, Thomas P., and A.Wren Montgomery. 2015. "The Means and End of Greenwash." *Organization and Environment* 28: 223–249.

Marquis, Christopher, Michael W. Toffel, and Yanhua Zhou. 2016. "Scrutiny, Norms, and Selective Disclosure: A Global Study of Greenwashing." *Organization Science* 27 (2): 483–504.

Miller, Nolan, David Molitor, and Eric Zou. 2017. "Blowing Smoke: Health Impacts of Wildfire Plume Dynamics." http://www.eric-zou.com/s/smoke_MMZ_201710.pdf.

re3data.org. “China Meteorological Data Service Center.” http://data.cma.cn (accessed September 2020).

Servaes, Henri, and Ane Tamayo. 2013. “The Impact of Corporate Social Responsibility on Firm Value: The Role of Customer Awareness.” *Management Science* 59: 1045–1061.

Sharfman, Mark P. and Chitru S. Fernando. 2008. “Environmental Risk Management and the Cost of Capital.” *Strategic Management Journal* 29(6): 569–592.

Sheldon, Tamara L., and Chandini Sankaran. 2017. “The Impact of Indonesian Forest Fires on Singaporean Pollution and Health.” *American Economic Review* 107(5): 526–529.

State of Global Air. 2020. Global Health Impacts of Air Pollution. https://www.stateofglobalair.org/health/global#key-diseases.

Tang, Dragon Y., and Yupu Zhang. 2020. “Do Shareholders Benefit from Green Bonds?” *Journal of Corporate Finance* 61, 101427.

Wharton Research Data Services. "China Stock Market & Accounting Research Database." https://wrds-www.wharton.upenn.edu/pages/about/data-vendors/china-stock-market-accounting-research-csmar/ (accessed September 2020).

Wind. “Financial Terminal.” https://www.wind.com.cn/en/wft.html (accessed September 2020).

Green Bonds, Air Quality, and Mortality

Evidence from the People's Republic of China

This study uses city-level data from the People's Republic of China to examine links between green bond market development and air quality as well as mortality rates. It finds that cities with more green bond financing as a share of total bond financing tend to have better air quality. The effect is stronger when certified green bonds are examined and in cities with higher gross domestic product growth. Further, local green bond issuance is also negatively related to mortality rates. The findings support the argument that green bond issuance is a credible signal of corporates' commitment to be environmentally responsible.

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