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OIL PRICE SHOCKS AND GREEN BONDS: A LONGITUDINAL MULTILEVEL MODEL

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Abstract

This paper contributes to the existing literature by investigating the impacts of crude oil price shocks on financial markets through an examination of the effect of oil price shocks on green bond issuance. Green bond issuance has been growing fast over the past several years; despite this, the share of green bonds in the total bonds remains small. Using the multilevel longitudinal random intercept and random coefficient models, this study investigates the effect of disentangled crude oil price shocks on green bond issuance in the private sector. Unlike the general bond market, our empirical analysis finds that oil supply shocks affect green bond issuance positively. We also find that the public issuance of sovereign green bonds tends to promote the private issuance of green bonds. Our results are robust and hold when using alternative models; they also survive a range of robustness tests.

Keywords: green bonds, sovereign bonds, green finance, oil shock, policy support, crude oil price

JEL Classification: Q28, Q42, Q48, G23

Contents

1. INTRODUCTION

In the next few decades, pronounced population growth is likely to occur, causing an increased demand for energy production, especially in developing countries. Therefore, it is important to create investment products that enable these countries to follow a path of low-carbon development. Green bonds, a recent innovation in sustainable finance, are a prominent financial instrument to raise capital for green projects (World Bank 2019a). The European Investment Bank (EIB) issued the first green bond in 2007, and its global capitalization reached $240 billion in 2019 (Bloomberg 2020). Still, the green bond market is in the nascent stage of development in terms of its popularity in developing countries, and the People's Republic of China, Germany, the United States (US), the Netherlands, and France accounted for 50% of the global issuance in 2019.

The existing literature has shown the connectedness between green investment and crude oil price shocks. Green assets are more vulnerable to volatility than to fluctuations in the oil price (Dutta, Jana, and Das 2020). While the use of corporate green bonds has become increasingly prevalent in practice, this financial instrument has a limited evident connection with the price movement in the conventional fuel market. This paper investigates the connection between the rationale behind firms issuing corporate green bonds and oil price shocks.

Ready (2018) proposed an approach to decomposing oil price shocks using global stock price data for oil-producing firms. This decomposition method has provided a reasonable amount of evidence regarding whether the effect of oil prices on financial markets occurs through shocks to the oil supply and demand (Demirer, Ferrer, and Shahzad 2020). To the best of our knowledge, the effect of oil prices on the issuance of green bonds remains unexplored. Unveiling this information would give policymakers a greater insight, enabling them to boost further the development of the green bond market to achieve the environmental goals.

This paper uncovers the relationship between oil price shocks and green bond issuance by studying the effects of oil price shocks on green bond issuance in the corporate sector in advanced and emerging economies. Some studies have tackled the effects of oil price shocks on bonds' returns and stock market valuation (Reboredo 2018; Demirer, Ferrer, and Shahzad 2020; Reboredo and Ugolini 2020); however, the effects of oil price shocks on the issuance of green bonds remain limited. To our best knowledge, this paper is the first empirical study to explore the driving factors of green bond issuance. It provides evidence-based policy recommendations for promoting the issuance of green bonds.

From the theoretical perspective, an increase in oil prices should increase the issuance of green bonds as it requires diversification of energy sources, especially for oil-importing economies, while a decrease in oil prices might have a decreasing effect on the issuance of green bonds as there is less pressure to promote renewable energy resources and continued reliance on the available fossil fuels. It is also interesting to track the effects of oil prices on green bond issuance in crude oil-exporting countries as lower oil prices provide incentives to diversify the economy further and hence require the promotion of renewable energy resources.

his paper investigates the drivers of private green bond issuance at two levels: countries and sectors. We examine the effect of crude oil shocks, which we decompose into demand, supply, and risk shocks, on green bond issuance. The results show that supply shocks have a positive impact on green bond issuance. Although the existing literature has predicted a negative impact of supply shocks, it has not studied the impact on green financial instruments. This paper provides a reference for the promotion of green bonds and the formulation of policies to promote the issuance of green bonds. The above findings survive two robustness tests: (a) using an alternative measure of oil price shocks; and (b) using an alternative specification of a regression model with the replacement of one control variable.

The structure of the rest of the paper is as follows. Section 2 reviews the studies on oil price shocks, clean energy stocks, and green investment. Section 3 provides a description of the data and methodology. Section 4 presents the results and the robustness tests. Section 5 provides conclusions and policy implications.

2. LITERATURE REVIEW: OIL PRICE SHOCKS

The large empirical literature on the relationship between oil prices and clean energy markets has mainly focused on clean energy stock prices (Henriques and Sadorsky 2008; Sadorsky 2012; Managi and Okimoto 2013). Earlier studies (Henriques and Sadorsky 2008; Sadorsky 2012) did not find a significant effect of oil price shocks on alternative energy stock prices. Using the VAR model, Henriques and Sadorsky (2008) studied the effects on the clean energy stock prices of shocks to oil prices, technology stock prices, alternative energy stock prices, and interest rates. The study did not find a significant effect of oil price shocks on alternative energy stock prices compared with shocks to technology stock prices, which have a positive and significant effect on alternative energy stock prices. Similarly, Sadorsky (2012) found higher dynamic conditional correlations between clean energy and technology stock prices than between clean energy stock prices and oil prices, suggesting that clean energy firms are less integrated with oil markets than with technology companies. A more recent study, Kyritsis and Serletis (2019), also showed that renewable energy stock returns are resilient to uncertainty in oil prices.

Building on these studies, subsequent empirical literature has contrasted the earlier studies with further evidence of a significant effect of oil prices on clean energy stocks (Kumar, Managi, and Matsuda 2012; Managi and Okimoto 2013; Reboredo, Rivera-Castro, and Ugolini 2017; Reboredo and Ugolini 2018; Kocaarslan and Soytas 2019; Pham 2019; Xia et al. 2019; Zhao 2020). Managi and Okimoto (2013) showed that oil prices had a positive effect on clean energy stock prices after the structural breaks at the end of 2007. Kumar, Managi, and Matsuda (2012) postulated that the oil and alternative energy prices should bear a positive relationship as increasing oil prices promote substitution away from conventional and toward alternative energy sources. Reboredo, Rivera-Castro, and Ugolini (2017) found that the relationship between oil prices and renewable energy stock returns is negligible in the short term but strengthens in the long term. In the long term, an increase in oil prices incentivizes renewable energy projects, while a decrease in oil prices diminishes the value of renewable energy companies. Similarly, Xia et al. (2019) found considerable substitution between fossil fuel resources and renewable energy.

Kocaarslan and Soytas (2019), studying the dependence of clean energy stock prices on oil prices, highlighted the significance of dollar fluctuations. They found that the appreciation of the US dollar is a major source of dynamic correlations between clean energy prices and oil prices. Asymmetric dynamic conditional correlations reinforce this mechanism. Pham (2019) presented an evidence-based analysis highlighting the heterogeneous responses of clean energy stocks to oil prices depending on the energy sector. The stock prices of biofuel and energy management firms exhibit the greatest connectedness to oil prices, while geothermal, wind, and fuel cell stock prices show the lowest oil price connectedness. Reboredo and Ugolini (2018), studying the effect of energy prices on new energy stocks, found that the effects of energy prices differ across regions; in the US, oil prices are mostly responsible for the movement in new energy stock prices, while, in the EU, the largest role is attributable to electricity prices. Zhao (2020) provided further evidence of the responsiveness of clean energy returns to oil price shocks by distinguishing between four types of shocks: oil supply shocks, aggregate demand shocks, policy uncertainty shocks, and oil-specific demand shocks. Zhao (2020) found that the effects of oil supply shocks on stock returns are positive, while the effects of oil demand shocks on clean energy stock returns are negative.

The studies on clean energy stock prices rely on the literature discussing the relationship between oil prices and stock returns in general. Smyth and Narayan (2018) provided a comprehensive survey of the studies tackling the effects of oil prices on stock returns. The theoretical literature is not conclusive regarding the effect of oil prices on stock returns, arguing that it depends on the investors' sentiments, future cash flows, expected inflation, and so on. The seminal study by Kilian and Park (2009) contemplated whether the effects of oil prices on stock returns depend on the nature of the shock. That depends on whether oil prices have asymmetric effects on stock returns, whether the relationship between oil prices and stock returns varies over periods of high and low volatility, and whether the response of stock returns to oil prices is heterogeneous across sectors, firms, net oil importers and net oil exporters, and so on (Smyth and Narayan 2018).

Another growing strand of literature has studied the connectedness of green investments, renewable energy consumption, and oil price shocks and the relationship between bonds and oil markets (Kang, Ratti, and Yoon 2014; Apergis and Payne 2015; Shah, Hiles, and Morley 2018; Dutta, Jana, and Das 2020; Kanamura 2020). However, it is not as large as the strand of literature on oil prices and stock returns. Dutta, Jana, and Das (2020), in their study on green investments, found that oil market volatility affects green assets more than oil price fluctuations. Shah, Hiles, and Morley (2018), studying the implications of oil prices for renewable energy investment in two oil-exporting countries, Norway and the UK, and an oil-importing country, the US, found a positive and significant effect of oil price shocks on renewable energy investment in the US and Norway and a negative and small effect in the UK. Apergis and Payne (2015) determined that real oil prices have a positive effect on renewable energy consumption using data for 11 South American countries from 1980 to 2010.

Kang, Ratti, and Yoon (2014), discussing the effects of the global demand and supply oil shocks, concluded that oil-related demand and supply shocks jointly contribute 30.6% of the variation in the US bond index real returns in the long run. Demand shocks play a significant role in the long-run variation of the Treasury bill returns. An oil price increase due to the uptake in the global aggregate demand reduces the bond market returns over 24 months. Kanamura's (2020) recent study investigated the dynamic correlations between green bond prices and oil prices. It found positive correlations between green bond returns and crude oil price returns, suggesting that green bonds have greenness features. However, to the best of our knowledge, it is the only study to have investigated the relationship between green bond returns and oil prices. No studies so far have considered the effects of oil price shocks on private green bond issuance, though the former are likely to influence the latter. Furthermore, no studies have discussed the effects of oil supply and demand shocks on private green bonds using Ready's (2018) identification strategy. Our study attempts to contribute to this strand of the literature by decomposing oil price shocks into demand and supply shocks and, as Smyth and Narayan (2018) discussed, we control for sectoral characteristics and whether the countries are exporters of oil, among other factors, in our study.

3. DATA

This paper estimates the impact of oil price shocks on private green bond issuance using monthly cross-country data from 46 green bond-issuing countries across nine sectors over the period January 2010 to June 2020. We collect the data for this study from Bloomberg Terminal, the World Bank, and the International Energy Agency (IEA) (Table 1) and structure them across three levels: (i) country, (ii) sector, and (iii) period (months). We select countries based on their green bond issuance during the period January 2010 to June 2020. We adopt the sector classification from the Bloomberg Industry Classification System for Fixed Income (BICS). Tables 1–3 present the summary statistics, data description, and correlation table. All the variables are balanced, monthly (except for annual GDP), and time varying over the study period.

Table 1: Data Description

Data	Bloomberg Description	Bloomberg Code
FTSE World Government Bond Index (MSCI World Stock Index)	Performance of fixed-rate, local currency, investment-grade sovereign bonds.	WGBI
NYMEX Crude Light Sweet Oil Futures Contract		WTI NYMEX CRUDE (CL1 COMB Comdty)
FTSE 350 Oil & Gas Producers Index	Capitalization-weighted index of all the stocks measuring the performance of the oil and gas producers' sectors.	F3OILG
FTSE All-Share Oil & Gas Producers Index	Capitalization-weighted index measuring the performance of the oil and gas producers' sectors. We use this variable to produce an alternative measure of oil shocks as a robustness check.	FAOILG
Chicago Board Options Exchange Volatility Index (VIX Index)	Financial benchmark designed to be an up-to-the-minute market estimate of the expected volatility of the S&P 500 Index, calculated using the midpoint of the real-time S&P 500 Index (SPX) option bid/ask quotes.	VIX Index
Private green bonds	Instruments of which the proceeds exclusively support new and existing green projects, defined as projects and activities that promote climate or other environmental sustainability purposes, excluding green bonds issued by the government.	GREEN (BICS1≠government)
Sovereign green bonds	Green bonds issued by the government	GREEN (BICS1=government)
Conventional bonds	All bonds	BONDS

Source: Own elaboration using Bloomberg terminal.

Table 2: Summary Statistics

Variable	Source	Obs.	Mean	Std Dev.	Min.	Max.
Private green bonds issued, share in all bonds (%)	Bloomberg terminal	21,013	1	11	0	100
Sovereign green bonds, billion $		18,060	11,602	45,896	0	1,664,071
Conventional bonds issued, ratio of GDP		21,013	0	1	0	27.25
World stock return		21,013	923	41	808.06	1,031.83
GDP per capita, thousand $	World Bank (2019b)	19,245	35	27	0.95	111.06
Exporter (net exporter of crude oil)	IEA (2019)	21,013	0	0	0	1
Oil Price Shock						
Risk shock	Own calculation using Bloomberg terminal	21,013	0	1	–2.75	4.39
Demand shock		21,013	0	0	–0.68	0.63
Supply shock		21,013	0	0	–3.03	3.06

Table 3: Correlation Matrix

N	Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	Private green bonds issued	1						
(2)	Conventional bonds issued	–0.0219	1					
(3)	Sovereign green bonds	0.0232	0.029	1				
(4)	GDP per capita	0.0394	0.3553	0.0609	1			
(5)	Risk shock	–0.0221	–0.0151	–0.0143	–0.0195	1		
(6)	Demand shock	0.0028	0.0123	–0.0166	–0.0037	–0.206	1	
(7)	Supply shock	0.0169	0.014	–0.0061	0.0066	–0.0846	0.2191	1
(8)	World stock return	0.084	–0.0072	0.0407	0.0642	–0.1389	0.1005	0.0344

4. METHODOLOGY

4.1 Dependent Variable

The dependent variable, issuance of *private green bonds*, is the share of green bond issuance, excluding the government's issuance, per month across sectors and countries in the total bond issuance, including conventional and green bonds. In green bonds, we include bonds with the label "green." Labeled green bonds are bonds that use the proceeds for green projects and have the green label (Climate Bonds Initiative (CBI) 2016). In this paper, we use Bloomberg's (2020) definition of green bonds, which expresses green bonds as "instruments for which the proceeds are exclusively applied (either by specifying Use of Proceeds, Direct Project Exposure, or Securitization) towards new and existing Green Projects, defined as projects and activities that promote climate or other environmental sustainability purposes." This list includes four types of green bonds: the Green Use of Proceeds Bond, the Green Use of Proceeds Revenue Bond, the Green Project Bond, and the Green Securitized Bond.

4.2 Crude Oil Shocks

We base crude oil shocks on our own calculations using the methodology of Kilian and Park (2009), Ready (2018), and Demirer, Ferrer, and Shahzad (2020). We decompose crude oil price shocks into demand, supply, and risk shocks.

Oil risk shock is a proxy for shocks to the discount rate (Ready 2018). The existing literature (Banerjee, Doran, and Peterson 2007; Ozoguz 2009; Zhu 2013; Demirer, Ferrer, and Shahzad 2020) has shown a negative impact of risk shocks on financial markets. It has explained this negative impact as "the adverse effect of a rise in risk aversion or the level of uncertainty on the risky equity market returns" (Demirer, Ferrer, and Shahzad 2020, 5).

Oil demand shock measures developments in the global aggregate demand. The existing literature (Kilian and Park 2009; Wang, Wu, and Yang 2013; Zhu et al. 2017; Basher, Haug, and Sadorsky 2018; Ready 2018; Demirer, Ferrer, and Shahzad 2020) has identified a positive impact of oil demand shocks on financial markets due to the growth in the global aggregate demand and the expansion of economic activities.

Oil supply shock reflects crude oil production disruption. The existing literature (Cunado and Perez de Gracia 2014; Chisadza et al. 2016; Demirer, Ferrer, and Shahzad 2020) has shown a negative effect of oil supply shocks on financial markets. A rise in the crude oil price would affect the "production costs for companies, reduce discretionary income and consumption expenditure of households, and raise inflationary expectations, with an adverse impact on economic activity and thus equity markets" (Demirer, Ferrer, and Shahzad 2020, 6).

We disentangle changes in oil prices in response to demand, supply, and risk shocks following the classification method of Ready (2018). We collect the data that we use for this decomposition from Bloomberg. Similar to Demirer, Ferrer, and Shahzad (2020), we use daily information on (i) the Oil and Gas Producer Index, the FTSE 350 Oil & Gas Producers Index (F3OILG); (ii) the NYMEX Crude Light Sweet Oil Futures Contract; and (iii) the Chicago Board Options Exchange Volatility Index (VIX). For the robustness check, we use the FTSE All-Share Oil & Gas Producers Index (FAOILG) instead of the Oil and Gas Producer Index (F3OILG Index) for calculating crude oil shocks.

We determine innovations in VIX as the residuals from an ARMA (1,1) model for the VIX index (Ready 2018), representing shocks related to the market discount rate, which correlate with risk attitudes. We identify demand shocks as the share of global stock index returns of crude oil companies that are orthogonal to the innovations in VIX. We obtain supply shocks as the residual oil prices that are orthogonal to both oil demand and risk shocks. We present Ready's (2018) decomposition model below:

$$X_t = AZ_t \tag{1}$$

with

$$X_t = [\triangle Oil\_price_t \quad Ret\_oil\_prod_t \quad \mu VIX_t],$$

$$A = \begin{bmatrix} 1 & 1 & 1 \\ 0 & a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{bmatrix}$$

and

$$Z_t = [s_t \quad d_t \quad \xi_{Vix,t}],$$

where $\triangle Oil\_price_t$ is the Oil and Gas Producer Index, $Ret\_oil\_prod_t$ is the nearest maturity NYMEX Crude Light Sweet Oil Futures Contract, μVIX_t is the Chicago Board Options Exchange Volatility Index (VIX), s_t is the crude oil supply shock, d_t is the crude oil demand shock, and $\xi_{Vix,t}$ is the crude oil risk shock.

In matrix form, we can write equation (1) as:

$$\begin{bmatrix} \triangle Oil_{price_t} \\ Ret_{oil_{prod}\,t} \\ \mu VIX_t \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} s_t \\ d_t \\ \xi_{Vix,t} \end{bmatrix}$$

where the Oil and Gas Producer Index:

$$\triangle Oil\_price_t = s_t + d_t + \xi_{Vix,t}, \tag{2}$$

the nearest maturity NYMEX Crude Light Sweet Oil Futures Contract:

$$Ret\_oil\_prod_t = a_{22} d_t + a_{23} \xi_{Vix,t}, \tag{3}$$

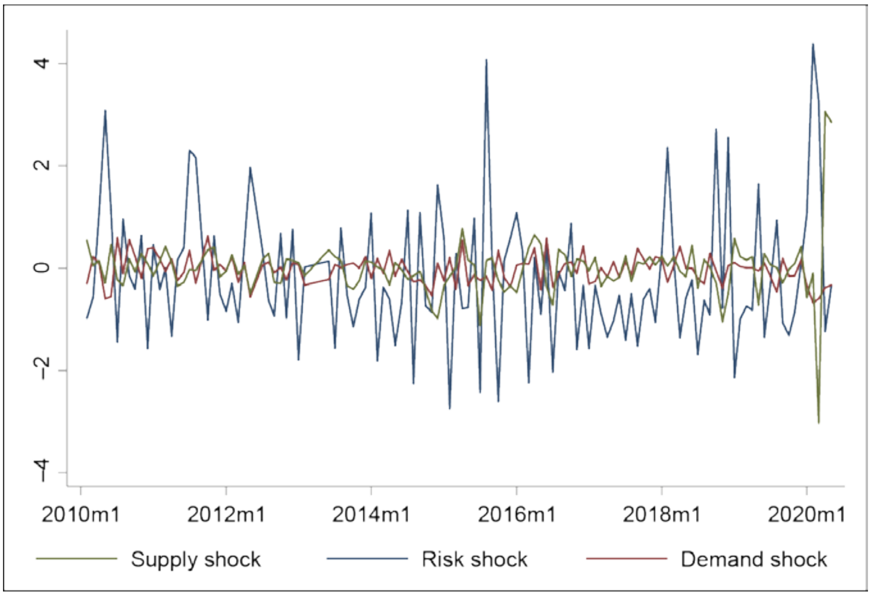
and the Chicago Board Options Exchange Volatility Index (VIX):

$$\mu VIX_t = a_{33} \xi_{Vix,t}. \tag{4}$$

Using equations (2), (3), and (4), we estimate the daily value of risk shocks ($\xi_{Vix,t}$), supply shocks (s_t), and demand shocks (d_t). We further aggregate the daily values at the monthly level.

We present our calculations of monthly crude oil shocks in Figure 1. All the shocks fluctuate around zero mean with differing volatility. The calculated risk shock is the most volatile, while the demand shock is the least volatile.

Figure 1: Oil Price Shock



Source: Own elaboration.

4.3 Control Variables

Apart from crude oil shocks, we use a set of explanatory variables that we expect to affect the issuance of green bonds. These explanatory variables are the public issuance of sovereign green bonds, issuance of conventional bonds, GDP per capita, world stock return, exporter, developing, oil supply shock, oil demand shock, and oil risk shock.

We measure the public issuance of *sovereign green bonds* as the value of green bonds that governments issue per month across countries. Sovereign green bonds include bonds that governments issue and that have the label "green." We could count the issuance of public green bonds as a government measure for supporting green bond issuance in the private sector. The public issuance of green bonds provides liquidity and initial market product pipelines as well as engaging and educating investors about green bonds (Azhgaliyeva, Kapoor, and Liu 2020).

The issuance of *conventional bonds* includes all bonds except green bonds. The impact of conventional bonds measures the presence of a trade-off between the issuance of conventional bonds and the issuance of green bonds. In this paper, we measure the issuance of conventional bonds as a share of the GDP.

World stock return is a global stock market index return, which we include in the model to control for the global market implications. The existing literature has shown the positive impact of world stock market returns on financial markets (Demirer, Ferrer, and Shahzad 2020).

Exporter is a binary variable, which equals one if the country's net exports of crude oil are positive and zero overwise. In the robustness test, we replace *exporter* with *developed*, a binary variable that equals one if the country is developed and zero overwise. Since our considered period is short, both variables, *exporter* and *developed*, do not vary over the years.

4.4 Estimation Strategy

The existing literature (Smyth and Narayan 2018; Pham 2019) has shown that the effect of oil shocks varies not only across countries but also across sectors. For example, the impact of oil shocks on the energy sector could be different from the impact on the financial sector. To control not only for country effects but also for sector effects, we collect data across countries, sectors, and months.

The data used for this study consist of two levels, with 46 countries at the first level and nine sectors at the second level, and vary across 125 months (Table 4) with 18,001 observations. We apply a multilevel model (Laird and Fitzmaurice 2013) to account for both cross-country/-sector and longitudinal effects (Skrondal and Rabe-Hesketh 2008) of our longitudinal multilevel data. We use four models for the analysis: multilevel models with a random intercept, fixed intercept, random coefficients, and fixed coefficients (see Table 5 for the test results).

First, we use the Hausman (1978) test to decide between the random-intercept and the fixed-intercept model. We reject the null hypothesis ($\chi^2 = 49.41$ with $Prob > \chi^2 = 0.00$); hence, the model with a random intercept is preferable.

Second, we use the likelihood ratio (LR) test to test for the presence of random coefficients, that is, $LR = -2(L_r - L_u)$, where L_r and L_u are the maximized log-likelihood values from the restricted and unrestricted models, respectively (Green 2012). Under the null hypothesis, the random slopes are zero, while they are non-zero under the alternative hypothesis. We reject the random-intercept model in favor of the random-intercept and random-coefficient model ($\chi^2(2) = 206.34$ with $Prob. > \chi^2 = 0.00$).

In addition, we test whether we should include unstructured covariance in the selected model. In the presence of the correlation between the intercepts and the slopes, we include unstructured covariance. We apply the likelihood ratio test to determine whether an unstructured covariance estimate is necessary. The results of the LR test reject the null hypothesis of the random intercept and random coefficient model ($\chi^2(1) = 1.74$ with $Prob. > \chi^2 = 0.78$); hence, we use the random-intercept and random-coefficient model with unstructured covariance.

The use of the likelihood ratio test versus the linear model (results in Table 6) aims to determine whether there is a multilevel model that is significantly different from the standard regression without group-level random effects.

Table 4: Multilevel Variables

Variables	Country Level (i)	Sector Level (j)	Time Level (t)	Notation
Private green bonds, share in all bonds	✓	✓	✓	$\frac{B_{ijt}^{GP}}{B_{ijt}}$
Conventional bonds, share in GDP	✓	✓	✓	$\frac{B_{ijt}^{C}}{Y_{it}}$
Sovereign green bonds	✓		✓	B_{it}^{GS}
GDP per capita	✓		✓	Y_{it}
Risk shock			✓	$\xi_{Vix,t}$
Demand shock			✓	d_t
Supply shock			✓	s_t
World stock return			✓	r_t

Source: Authors' own elaboration.

Based on the results of the above tests, the random-intercept and random-coefficient model is the preferred model. This model has the following specification:

$$\frac{B_{ijt}^{GP}}{B_{ijt}} = \mu_j + \beta_1 d_t + \beta_2 s_t + \beta_3 \xi_{Vix,t} + \beta_4 \frac{B_{ijt}^{C}}{Y_{it}} + \beta_5 B_{it}^{GS} + \beta_6 Y_{it} + \beta_6 r_t + \varepsilon_{ijt}, \quad (5)$$

where $i = 1, \ldots, 46$ indexes countries, $j = 1, \ldots, 9$ indexes sectors, and $t = \text{Jan } 2010, \ldots, \text{Jun } 2020$ indexes months, $\frac{B_{ijt}^{GP}}{B_{ijt}}$ is the share of corporate (private) green bond issuance over all bonds, d, s, $\xi_{Vix,t}$ are oil-related demand, supply, and risk shocks, respectively, $\frac{B_{ijt}^{C}}{Y_{it}}$ is the issuance of conventional bonds as a share of the GDP, B_{it}^{GS} is the issuance of sovereign green bonds, μ_j are unit-specific intercepts of fixed effects, and ε_{ijt} are normally independent and identically distributed (i.i.d.) with mean $E(\varepsilon_{ijt}) = 0$. In the random intercept model, μ_j and ε_{ijt} are independently distributed with $\mu_j \sim N(0, w^2)$ and $\varepsilon_{ijt} \sim N(0, \sigma^2)$.

Table 5: Test Results

Test	Null Hypothesis (H0)	Alternative Hypothesis (H1)	χ^2	$Prob. > \chi^2$	Result
Hausman test	FI	RI	49.41***	0.0000	RI
Likelihood ratio test	RI	RI RC	206.34***	0.0000	RI RC
Likelihood ratio test	RI RC	RI RC UC	1.74	0.7832	RI RC

Note: FI – fixed intercept; RI – random intercept; RC – random coefficient; UC – unstructured covariance.

Source: Authors' own elaboration.

5. EMPIRICAL RESULTS AND DISCUSSION

5.1 Main Results

The main results of the random-intercept and random-coefficient model, which the above tests identified as the preferred model, are presented in columns (4)–(6) of Table 6. Based on the Hausman (1978) test and the LR test results, the preferred model is the random-intercept and random-coefficient model (Eq. 3). For comparison, Table 6 also contains the results from other models: random intercept (columns 1–3) and random intercept and random coefficient with unstructured covariance (columns 7–9).

We find that *supply shocks* have a positive impact on private green bond issuance. Although, to our best knowledge, the existing literature has not assessed the impact of crude oil shocks on green bonds, this finding is aligned with the literature studying the impact of crude oil supply shocks on the stock returns of clean energy corporations (Zhao 2020), renewable energy investment (Shah, Hiles, and Morley 2018), and renewable energy consumption (Shah, Hiles, and Morley 2018). Crude oil price supply shocks make renewable energy projects more attractive than fossil fuel projects, which leads to greater investment in green projects (Shah, Hiles, and Morley 2018) and stock returns of clean energy corporates (Zhao 2020) and thus increase green bond issuance. On the other hand, this result is contradictory to those of other studies that did not separate the impact on the green financial market (Cunado and Perez de Gracia 2014; Chisadza et al. 2016; Demirer, Ferrer, and Shahzad 2020). The results show that the impact of an oil supply shock on the green market is opposite to the impact of an oil supply shock on the non-green financial market. We find that oil supply shocks promote green bond issuance. Even though the majority of the countries that we included in the sample are net oil-importing nations, the impact of oil supply shocks on green bond issuance is still positive.

We observe that *demand shocks* have no impact on the private issuance of green bonds. This in contrast to the existing literature, which predicted a negative impact of an oil demand shock on clean energy stock returns (Zhao 2020) and a positive impact on the financial market (Kilian and Park 2009; Wang, Wu, and Yang 2013; Zhu et al. 2017; Basher, Haug, and Sadorsky 2018; Ready 2018; Demirer, Ferrer, and Shahzad 2020). Our results show that oil demand shocks have no significant impact on green bond issuance.

We find that *risk shocks* (a proxy for discount rate shocks) have no significant impact on green bond issuance. The impact is negative but statistically not significant. Risk shocks show an adverse effect on the level of uncertainty. This result is different from the literature studying financial markets, which predicted a negative impact (Banerjee, Doran, and Peterson 2007; Ozoguz 2009; Zhu 2013; Demirer, Ferrer, and Shahzad 2020).

Examining the role of policy support in green bond issuance, we observe that the public issuance of *sovereign green bonds* incentivizes the private sector's issuance of green bonds. This is aligned with Dittmar (2008), who showed that sovereign bonds promote the corporate bond market in emerging economies. The issuance of sovereign green bonds has a positive and significant impact on the issuance of private green bonds. This result is as we expected because the public issuance of green bonds provides liquidity and initial market product pipelines. It also promotes the demand for green bonds by engaging investors and educating them about green bonds (Azhgaliyeva, Kapoor, and Liu 2020). The public issuance of green bonds provides examples, acts as a benchmark, and guides the private sector to issue green bonds. In addition, the public issuance of green bonds demonstrates the existence of the demand for green bonds and increases liquidity by expanding the supply of green bonds. In this paper, we measure the issuance of sovereign green bonds in billions of US dollars. Public issuance of green bonds of $10 billion per month increases the share of green bonds in the total bonds by 1.8–1.9%. Sovereign green bonds do not "crowd out" private green bonds but rather "crowd in" private green bonds.

We find that net-exporting countries of crude oil issue 18.39% fewer green bonds as a share of all bonds compared with net-importing countries. The interaction terms of *exporter* with crude oil shocks are not significant. This result is consistent with Demirer, Ferrer, and Shahzad's (2020) study, which showed that the impact of crude oil shocks on financial markets does not depend on importers/exporters. Crude oil prices encompass expectations regarding global growth and do not merely reflect imported/exported fuel (Demirer, Ferrer, and Shahzad 2020).

We find that the total value of *conventional bond* issuance per month has no impact on green bond issuance. This points to the absence of a trade-off between conventional and green bond issuance.

5.2 Robustness Checks

This section checks the robustness of our major results. We test whether the findings regarding oil price shocks' effect on green bond issuance is robust to (a) an alternative specification of oil price shocks and (b) alternate specifications of the regression model with different control variables. Table A.1 in the Appendix reports the results.

5.2.1 Alternative Measure of Oil Price Shocks

We use an alternative specification of crude oil shocks to test the robustness of our earlier findings. We calculate the alternative measure of crude oil shocks using *F3OLIG* instead of *FAOILG*. The results show that, with an alternative measure of crude oil shocks, the results (column 3 of Table A.1 of Appendix A) are consistent with our main results (column 2 of Table A.1). The significance and sign of all the coefficients using the alternative measure of oil shocks are the same as in our main results. The results are robust to alternative measures of crude oil shocks; we find that oil supply shocks have a positive impact on private green bond issuance and sovereign green bond issuance has a positive impact on private green bond issuance.

5.2.2 Alternative Specification of the Regression Model

We test the robustness of our results by replacing the *export* control variable and its interaction terms with *developed* and its interaction terms with crude oil shocks. Table A.2 in the Appendix reports the results. We find that our results using *developed* instead of *exporter* (column 5 of Table A.1) are consistent with our main results (column 4 of Table A.1). Both models provide coefficients of most variables with the same significance and sign.

Table 6: Results

Variables	(1) RI	(2) RI	(3) RI	(4) RIRC	(5) RIRC	(6) RIRC	(7) RIRC UC	(8) RIRC UC	(9) RIRC UC
Conventional bond, share of GDP	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sovereign green bonds, billion $	0.21**	0.20**	0.20**	0.19*	0.18*	0.18*	0.19*	0.18*	0.18*
	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
GDP per capita, thousand $	0.22***	0.11***	0.11***	0.33***	0.24***	0.24***	0.33***	0.24***	0.24***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Return on world stock		0.02***	0.02***		0.01***	0.01***		0.01***	0.01***
		(0.00)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)
Exporter			0.30			–18.39***			–18.39***
			(1.65)			(3.49)			(3.49)
Oil price shock									
Risk shock		–0.06	–0.09		–0.05	–0.08		–0.05	–0.08
		(0.05)	(0.06)		(0.05)	(0.06)		(0.05)	(0.06)
Demand shock		–0.29	–0.27		–0.24	–0.22		–0.24	–0.22
		(0.24)	(0.29)		(0.25)	(0.29)		(0.25)	(0.29)
Supply shock		0.30	0.41*		0.32*	0.42*		0.32*	0.42*
		(0.19)	(0.22)		(0.19)	(0.22)		(0.19)	(0.22)
Sectors									
Consumer				0.10	0.10	0.10	0.10	0.10	0.10
				(1.15)	(1.15)	(1.15)	(1.15)	(1.15)	(1.15)
Energy				3.64***	3.62***	3.62***	3.64***	3.62***	3.62***
				(1.18)	(1.18)	(1.18)	(1.18)	(1.18)	(1.18)
Financial				–0.59	–0.57	–0.57	–0.59	–0.57	–0.57
				(1.13)	(1.13)	(1.13)	(1.13)	(1.13)	(1.13)
Health				0.17	0.16	0.16	0.17	0.16	0.16
				(1.25)	(1.25)	(1.25)	(1.25)	(1.25)	(1.25)
Industrial				2.01*	1.98*	1.98*	2.01*	1.98*	1.98*
				(1.17)	(1.17)	(1.17)	(1.17)	(1.17)	(1.17)
Materials				0.38	0.37	0.37	0.38	0.37	0.37
				(1.18)	(1.17)	(1.17)	(1.18)	(1.17)	(1.17)
Technology				–0.24	–0.25	–0.26	–0.24	–0.25	–0.26
				(1.28)	(1.28)	(1.28)	(1.28)	(1.28)	(1.28)
Utilities				6.68***	6.63***	6.63***	6.68***	6.63***	6.63***
				(1.16)	(1.16)	(1.16)	(1.16)	(1.16)	(1.16)
Country control				✓	✓	✓	✓	✓	✓
Constant	–4.54***	–14.99***	–15.05***	–4.86**	–15.44***	–15.44***	–4.86**	–15.44***	–15.44***
	(1.32)	(1.65)	(1.71)	(1.94)	(2.41)	(2.41)	(1.94)	(2.41)	(2.41)
LR test vs. linear model, χ^2	579***	578***	579***	577***	579***	578***	579***	577***	579***

Note: Standard errors in parentheses. We drop solar to avoid the multicollinearity problem. We exclude the coefficients of country and renewable energy dummy variables from the table but indicate their presence with “Yes.” We include variables affecting total private investment, that is, the real effective exchange rate, inflation rate, interest rate, political stability and absence of violence/terrorism index, gross domestic product, trade, and domestic credit to the private sector, in the estimation but exclude them from the results table. RI – random intercept, FI – fixed intercept, RC – random coefficient, FC – fixed coefficient, u.c. – unstructured covariance, and LR – likelihood-ratio test. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. 18,001 observations from 46 countries.

6. CONCLUSION

This study utilizes multilevel models to estimate the impact of crude oil shocks, conventional bond issuance, and sovereign green bond issuance on the private sector's green bond issuance. We reach two important conclusions. Crude oil shocks stimulate the private sector to issue green bonds. The result is the opposite to the impact of oil shocks on general (non-green) financial markets. The green financial market benefits from oil supply shocks. In addition, sovereign green bonds tend to promote private green bonds. This shows the importance of government support and the need for policies that reduce the costs and risks of green bond issuance, especially for first-time issuers. Our findings survive several robustness tests.

This study implies that national governments and bond issuers need to understand better the global and domestic factors that influence and support green bond development, thus providing policymakers with robust evidence of the need to incorporate global supply shocks of crude oil and the issuance of sovereign green bonds while preparing further instruments to boost green growth.

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APPENDIX A

This appendix reports the results of the robustness tests. We test the consistency of the results with: (1) an alternative specification of crude oil shocks; and (2) additional control variables.

Table A.1: Robustness Tests

	Robustness Test 1		Robustness Test 2	
Variables	**Shock**	**Alternative Shock**	**Exporter**	**Developed**
Conventional bonds, share of GDP	–0.00	–0.00	–0.00	–0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Sovereign green bonds, billion $	0.18*	0.18*	0.18*	0.18*
	(0.10)	(0.10)	(0.10)	(0.10)
GDP per capita, thousand $	0.24***	0.24***	0.24***	0.24***
	(0.03)	(0.03)	(0.03)	(0.03)
Oil risk shock	–0.08	0.03	–0.00	0.03
	(0.06)	(0.06)	(0.08)	(0.06)
Oil demand shock	–0.22	–0.06	–0.24	–0.06
	(0.29)	(0.24)	(0.37)	(0.24)
Oil supply shock	0.42*	0.54**	0.23*	0.54**
	(0.22)	(0.16)	(0.28)	(0.16)
World stock market return	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
Exporter	–18.39***	–18.22***	–0.10	
	(3.49)	(3.49)	(2.63)	
Interaction term with exporter: risk shock	0.10	0.01	–0.08	
	(0.12)	(0.10)	(0.11)	
Interaction term with exporter: demand shock	–0.06	–0.37	0.01	
	(0.54)	(0.47)	(0.49)	
Interaction term with exporter: supply shock	–0.36	0.10	0.16	
	(0.42)	(0.36)	(0.38)	
Developed				–0.04
				(2.63)
Interaction term with developed: risk shock				–0.10
				(0.07)
Interaction term with developed: demand shock				–0.32
				(0.34)
Interaction term with developed: supply shock				0.43*
				(0.26)
Country control	✓	✓	✓	✓
Sector: Consumer	0.10	0.10	0.10	0.10
	(1.15)	(1.15)	(1.15)	(1.15)
Sector: Energy	3.62***	3.62***	3.62***	3.62***
	(1.18)	(1.18)	(1.18)	(1.18)
Sector: Financial	–0.57	–0.57	–0.57	–0.57
	(1.13)	(1.13)	(1.13)	(1.13)
Sector: Health	0.16	0.15	0.17	0.15
	(1.25)	(1.25)	(1.25)	(1.25)
Sector: Industrial	1.98*	1.97*	1.99*	1.98*
	(1.17)	(1.17)	(1.17)	(1.17)
Sector: Materials	0.37	0.37	0.37	0.37
	(1.17)	(1.17)	(1.17)	(1.17)
Sector: Technology	–0.26	–0.27	–0.25	–0.25
	(1.28)	(1.28)	(1.28)	(1.28)
Sector: Utility	6.63***	6.63***	6.62***	6.63***
	(1.16)	(1.16)	(1.16)	(1.16)
Constant	–15.44***	–15.35***	–15.43***	–15.34***
	(2.41)	(2.43)	(2.41)	(2.42)

Note: Standard errors in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. 18,001 observations from 46 countries.

APPENDIX B: SUPPLEMENTARY DATA

We base the estimated values of shocks and the codes that this paper uses on Ready (2018) and submit them with this paper.