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Full Length Article

Oil prices and the green bond market: Evidence from time-varying and quantile-varying aspects

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Abstract

This paper investigates the link between crude oil prices (COP) and green bonds through a rolling-window Granger-causality test. The positive, negative, and uncorrelated impacts of COP on the green bond index (GBI) are captured with the same sample. The positive effects show that the prosperity of the green bond market is promoted by the high COP, demonstrating that green bonds can avoid shocks from COP. Nevertheless, due to the high profits of the green energy industry and the excess supply on the oil market, the negative impact between COP and GBI is also found. These results are not completely consistent with the price correlation model between oil and green bonds. Furthermore, the positive impact of the GBI on COP shows that green bonds cannot moderate the oil crisis due to COVID-19, instability in the international political environment, and the immaturity of green bonds market. In addition, depending on the quantile Granger-causality test, only high COP affects the GBI, and this asymmetric feature is attributed to increasing production costs and environmental protection pressure. Understanding the nexus between COP and the GBI is of practical significance for bond issuers, regulators, and investors.

JEL classification: C22; G10; Q43

Keywords: Causal relationship; Green bonds; Oil price; Time varying

1. Introduction

This study investigates the possibility that crude oil prices (COP) could influence the future of green bonds. Energy is the foundation of the economy, and a stable supply of energy is necessary to support constant economic expansion or guarantee national security (Peng et al., 2021; Song et al., 2019). Oil, called the lifeblood of industry, is crucial for economic progress (Wang et al., 2022a). However, oil is actually a scarce and unequally divided resource, mostly among countries with fragile political systems (Wang et al., 2021). Energy security challenges have resulted from worldwide conflicts caused by countries competing for oil (Colgan, 2013). In addition to being in low supply, fossil fuels also have environmental issues. The combustion of fossil fuels releases greenhouse gases (GHGs), which play a role in climate change (Bondia et al., 2016; Wang et al., 2022b; Yuan et al., 2022). World population growth drives energy demand, and countries worldwide are prioritizing energy reforms more than ever (Sun et al., 2022). Governments must actively promote green energy technologies and invest significantly in renewable energy. Additionally, it is essential to develop vehicles powered by non–fossil fuels quickly to decrease the need for cars with

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internal combustion engines and reduce reliance on oil (Su et al., 2021). The private sector is not particularly motivated to invest in green projects over the long run because of their poor yield and unique dangers; therefore, these countermeasures need a lot of financial backing (Yoshino et al., 2019). Consequently, the world must produce a financial instrument for raising money and hastening the pace of the transition to low-carbon energy sources (Wang et al., 2022c). "Green bonds" help support environmentally friendly initiatives and advance sustainable development. Finding alternative energy sources is essential because of continuously fluctuation in COP (Buyukozkan & Guleryuz, 2016). The increasing COP inexorably stimulates clean energy investment because most of the money from green bonds is used to build clean energy projects. This encourages the issuing and purchasing of green bonds (Tian et al., 2022). Additionally, green bonds offer investors more diversified investment alternatives as a means of financing the energy transition and a hedging asset. Since the financial crisis in 2008, financial markets have suffered because of the extremely volatile nature of COP (Zhang, 2017). Increases in COP frequently occur in conjunction with inflation, lowering real yields and undermining investor trust (Alao & Payaslioglu, 2021; Kilian & Zhou, 2022). Therefore, understanding the links between green bonds and oil prices is important for investors, regulators, and bond issuers.

Issues with GHG emissions emerge where fossil fuels are burned to provide energy (Swails et al., 2022). If the use of fossil fuels continues at its present rate, the environment and humanity will be seriously imperiled by the highly negative effects of climate change (Lu et al., 2022). Decreased investment in fossil fuels and higher funding for green energy initiatives are necessary to hasten the transition to an environmentally friendly economy (Gao et al., 2022; Tu et al., 2021). As a result, green bond issuers and investors will have access to new financial opportunities. Issuers can obtain sufficient funding to develop green energy projects, and investors can receive predictable returns through interest (Chatziantoniou et al., 2022). Green bonds are evolving as a new concept in sustainable financing in response to environmental degradation and energy security (Meo & Karim, 2021). The high COP impacts the future of green bonds because it sparks investor interest and motivates issuers to continue issuing bonds. Air and water pollution and the depletion of natural resources are side effects of the use of fossil fuels (Yang et al., 2022). Because renewable energy can replace crude oil (Fu & Ng, 2021), its advancement in the face of rising oil prices has gained worldwide support (Guo et al., 2021). Shah et al. (2018) examine the effect of COP on investment in renewable energy and discover that the effect in the US is beneficial and significant. To promote the green transition financially, the European Union (EU) offers green bonds. The primary reason that multilateral development banks issue green bonds is to finance renewable energy projects. This study investigates whether COP will energize the market for green bonds, which would be crucial for green bondholders and issuers. Issuers can base their judgments on COP, and investors can understand how COP affects environmental investment and create the best investment portfolios for risk diversification.

We find that the causal relationship between COP and the GBI is time varying and reveal positive, negative, and even noncausality in the same sample, mainly due to government intervention, the COVID-19 pandemic, the development of green industry and other factors. Meanwhile, the GBI is found to be sensitive only to high oil prices, and this asymmetry might be due to increasing production costs and pressure to protect the environment. Therefore, this study makes the following contributions. First, previous literature does not achieve consensus about the oil–green bond nexus. Some papers argue that a positive relationship exists (Lee et al., 2022; Tian et al., 2022), while others hold the opposite opinion (Huang et al., 2022). Yan et al. (2022) find a causal link between energy prices and green bonds, but the direction of influence is not revealed. The various conclusions can be attributed to the assumption of linearity in the estimation; so this paper uses the rolling-window method to detect time-varying causality, which can reveal positive, negative, and noncausal time quantum over the sample period. Second, being beneficial because of the time-varying characteristic of causality, we enhance the theoretical framework for COP and the GBI. The price correlation model (Kanamura, 2020) argues that oil prices and green bonds are related, but the evidence from our empirical results does not always support that model. Deviations from the model are found for multiple potential reasons, such as global economic conditions and government subsidies. Thus, differentiated policies are necessary for governments, institutions, and investors against different phase characters and potential shocks. Third, this paper focuses on China as an important example. Most of the research to date focuses on green bond markets in developed countries (Azhgaliyeva et al., 2022; Lee et al., 2021), but little attention is paid to China, the biggest developing country yet the biggest oil importer and a major green bond issuer. Thus, this paper fills a research gap by comprehensively discussing the relationship between COP and China's green bond market.

The rest of this paper is arranged as follows. Section 2 reviews the relevant literature. Section 3 presents the theoretical framework. Sections 4 and 5 introduce the method and data. Section 6 shows the empirical results. Section 7 summarizes our conclusions and offers the policy implications.

2. Literature review

2.1. Green bond market

Green bonds are an important component of green finance and a new financial asset (Mensi et al., 2022). According to the Climate Bond Initiative Report 2021, total global green bond issuance increased by about US350 billion in 2020, which is double the level in 2018 (Lin & Su, 2022). Green bonds support environmental projects related to reducing emissions of carbon dioxide (CO_2) and conserving energy (Trompeter, 2017). The current research on the green bond market can be divided into two streams. The first tries to increase the transparency of guidance and regulation of the green bond market (Deschryver & Mariz, 2020; Tu et al., 2020; Zhang, 2020). The second stream investigates dynamic pricing of green bonds and provides valuable references for investment (Broadstock & Cheng, 2019; Fatica et al., 2021; Li et al., 2022; Liu, 2022; Pham, 2016).

Among developing countries, China has experienced a remarkable expansion in the green bond market. The scale of issuance increased rapidly, from nearly US$0 in 2015 to US$37 billion in 2017 (Elliott & Zhang, 2019). In 2019, China and the US were the top two issuers of bonds labeled as green (Liu et al., 2022). For China, the reasons for this phenomenon can be attributed to a series of hard laws and a top-down development model (Huang & Yue, 2019). However, the development of the green bond market shows evident regional heterogeneity; coastal areas with high levels of economic development perform better (Liu et al., 2022). Moreover, in 2020, about 45.8 percent of new issues did not follow the definition of green bonds (Xu et al., 2022).

2.2. Oil prices and green bonds

Initially, considerable efforts were made to focus on the relationship between oil prices and the bond market (Balcilar et al., 2020; Dai & Kang, 2021; Kang et al., 2014; Lee & Kim, 2022; Morrison, 2019; Nazlioglu et al., 2020). Because of the rising awareness of the need for environmental protection and the development of cross-course between the environment and finance, more research attention gradually turned to green bonds. Kanamura (2020) show that the S&P and Bloomberg Barclays MSCI tend to be positively correlated with Brent and West Texas Intermediate (WTI) oil prices and rise with them. Lee et al. (2021) observe bidirectional causality from oil prices to the GBI. Azhgaliyeva et al. (2022) find that oil price shocks have a significant and positive influence on the probability of the issuance of green bonds. Taghizadeh-Hesary et al. (2021) hold that a decrease in oil prices reduce motivation for developing renewable energy, which is negative for developing green bonds. Huang et al. (2022) argue that green bonds are negatively correlated with COP. However, some papers present different views. When the oil and green bond markets are bullish, COP has a weak influence on the GBI (Lee et al., 2021). In particular, relevant studies have focused on China, given the remarkable performance of its green bond market. Li et al. (2022) indicate that COP has a negative effect on the GBI in the short and medium term. Lee et al. (2022) also show that positive changes in COP cause a reduction in green bond returns. Su, Chen, et al. (2022) state that the positive link between oil prices and green bonds in the short term become negative in the long term. Deus et al. (2022) emphasize that China's green bond market is subject to more comprehensive green policies, which reduces the influence of external shocks, such as oil price volatility and ensure a green transition.

In general, the existing literature focuses on the green bond market, such as market management, guidance, challenges, and opportunities (Lin & Su, 2022; Mensi et al., 2022). Although emerging studies have started to branch out to other topics, the number of studies is insufficient, no consensus has been reached about the nexus between green bonds and COP. Positive, negative, and irrelevant results are achieved in various papers (Azhgaliyeva et al., 2022; Huang et al., 2022). The potential reason is that some authors assume that only one kind of relationship can exist during the sample period and is constant (Wang et al., 2022a). So, our empirical analysis focuses on China, because little attention has been paid to its rapid development of the green bond market. Some papers discuss relevant topics (Lee et al., 2022; Su, Chen, et al., 2022), but a systemic research framework has not been constructed. Therefore, this paper fills a research gap in the following ways. The most important point is that positive, negative, and irrelevant bidirectional relationships between green bonds and COP can be captured simultaneously during the sample period. That provides more heterogeneous and comprehensive conclusions such as different influencing directions in the same sample. Our focus on China has practical significance for regulatory agencies and investors in developing countries.

3. Theoretical framework

The relationship between oil prices and green bonds can be explored by the demand-supply model, proposed by Kanamura (2020). The equilibrium prices of COP_t and GBI_t are as follows:

$$COP_t = \left(1 + \alpha_1 \frac{D_t}{c_1}\right)^{1/\alpha_1} \quad (1)$$

$$GBI_t = \left(1 + \alpha_2 \frac{\overline{S}_t - S_t}{c_2}\right)^{1/\alpha_2} \quad (2)$$

$$dD_t = \mu_D dt + \sigma_D dw_t \quad (3)$$

$$dS_t = \alpha(COP_t) dD_t + \sigma_V dz_t \quad (4)$$

where COP_t is represented by Equation (1), and demand is shown by volume D_t in Equation (3). In the presence of short-run green bond price inelasticity of supply, GBI_t is presented in Equation (2), and the supply is shown by volume S_t in Equation (4). $\overline{S}_t$ denotes the upper limit of S_t and is a constant. In order to explore the effects of oil prices on green bonds, it is assumed that the volume in the GBI is impacted by COP through $\alpha(COP_t)$ in Equation (4), noting that $E_t[dw_t dz_t] = \rho dt$. Following Ito's lemma, we have:

$$\overline{\sigma}_{GBI} = \sqrt{\alpha(COP_t)^2 \sigma_D^2 + \sigma_S^2 - 2\rho\alpha(COP_t)\rho_D\rho_S} \quad (5)$$

$$\rho_{COP-GBI} = \frac{1}{dt} corr\left(\frac{dGBI_t}{GBI_t}, \frac{dCOP_t}{COP_t}\right) = -\frac{\alpha(COP)\sigma_D + \rho\sigma_S}{\overline{\sigma}_{GBI}} \quad (6)$$

This is the correlation model of oil prices and green bonds. COP is determined by supply and demand. Note that $\rho_{COP-GBI}$ is positive when $-\alpha(COP)\sigma_D + \rho\sigma_S > 0$. Meanwhile, there is the following equation is shown,

$$\frac{\partial \rho_{COP-GBI}}{\partial COP} = -\frac{\sigma_D \sigma_S^2}{\overline{\sigma}_{GBI}^3}\left(1-\rho^2\right)\frac{\partial \alpha}{\partial COP} \tag{7}$$

when $\frac{\partial \alpha}{\partial COP} < 0$, and ρ_{OG} is an increasing function of COP, which reveals that the relationship between green bonds and oil price becomes more significant when the oil price is higher (Ayres & Ayres, 2009). A high COP prompts substitution effects from petroleum to alternative energy sources, which helps the green bond market. This model demonstrates the price correlation between green bonds and oil commodities, referred to as the model by Kanamura (2020), which includes a correlation model with supply and demand–based oil prices, and the supply of green bond assets is influenced by the amount of oil demanded. However, according to the correlation model, the relationship between COP and the GBI exists, but the direction cannot be confirmed.

Based on the model, in a high-demand market, more energy consumption will be used when COP is high (Henriques & Sadorsky, 2011). In the supply market, the cost increases with high COP, and critical inputs and output are reduced (Dutta, Jana, & Das, 2020). The fluctuations in COP affect the green bond market. Positive volatility in the oil market encourages the benefits of and incentives for green investment, increasing the value of green bonds (Brown & Yücel, 2002). However, the rewards of green bond investment decrease when COP trends downward (Bondia et al., 2016; Xia et al., 2019).

4. Methodology

In line with the supply and demand–based correlation model, the relationship between COP and the GBI exists but the direction cannot be confirmed. Thus, to investigate the bidirectional causality between the GBI and COP and to address the problem of nonconstant interaction and time-varying causality, we use the Balcilar et al. (2010) method in this study.

4.1. Bootstrap full-sample causality test

In the estimation of vector autoregression (VAR), the statistics from the Granger-causality test caused by nonstationary time-series data have a nonstandard asymptotic distribution. The critical value of the bootstrap (*RB*) method based on residuals can be used to solve the problems of biased results and test capability (Shukur & Mantalos, 1997). In addition, the likelihood ratio (*LR*) test can adjust the characteristics of its power and size (Shukur & Mantalos, 2000). Therefore, this study uses a special technique to better study interactions between the GBI and COP. Using the *RB*-based modified-*LR* test, we constructed a VAR (p) system for these variables as follows:

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \ldots\ldots + \beta_p Y_{t-p} + \mu_t \qquad t = 1, 2, \ldots\ldots, T \tag{8}$$

The value of p is the optimal lag order, which is determined according to the Schwarz information criterion (SIC). We divide Y_t in the VAR (p) system into the GBI and COP, which is expressed as $Y_t = (GBI_t, COP_t)'$. In addition, the GBI and COP may have a correlation affected by the US dollar index (USD) because these two variables are simultaneously affected by volatility (Anjum, 2019; Kocaarslan, 2021; Mcleod & Haughton, 2018). Considering these two variables, we summarize the VAR model with a control variable (USD) (Dai et al., 2021) in Equation (8):

$$\begin{bmatrix} GBI_t \\ COP_t \end{bmatrix} = \begin{bmatrix} \beta_{10} \\ \beta_{20} \end{bmatrix} + \begin{bmatrix} \beta_{11}(L) & \beta_{12}(L) & \beta_{13}(L) \\ \beta_{21}(L) & \beta_{22}(L) & \beta_{23}(L) \end{bmatrix} \begin{bmatrix} GBI_t \\ COP_t \\ USD_t \end{bmatrix} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix} \tag{9}$$

where the function $\mu_t = (\mu_{1t}, \mu_{2t})'$ shows the white noise process with a zero mean. $\beta_{ij}(L) = \sum_{k=1}^{p} \beta_{ij,k} L^k$, $i, j = 1, 2$ and L is a lag operator, defined as $L^k Y_t = Y_{t-k}$.

The null assumption that COP has no effect on the GBI, that is, $\beta_{12,k} = 0$ for $k = 1, 2, \ldots. p$, so we conduct a correlation test in accordance with Equation (9). Based on the results, we can see that accepting COP does not Granger cause the GBI. In the same way, the null assumption that the GBI will not lead to COP ($\beta_{21,k} = 0$ for $k = 1, 2, \ldots. p$) can be examined by imposing restrictions.

4.2. Parameter stability test

A full-sample test is not a feasible method because the assumption that the parameters are constant and stable does not conform with reality. Following this revelation, a test of *Sup-F*, *Ave-F,* and *Exp-F* can be used. *Sup-F* is used to examine whether structural changes exist. Further, *Ave-F* and *Exp-F* are adopted to test whether the parameters change over time (Andrews, 1993; Andrews & Ploberger, 1994). Because of the time-varying parameters, we rely on the application of the bootstrap subsample rolling-window method to avoid unreliable results in a full-sample causality test.

4.3. Bootstrap subsample rolling-window causality test

The method divides the full time series into small samples in accordance with the width of the rolling window and rolls gradually from the beginning to the end of the sample. It was developed by Balcilar et al. (2010) and Su, Pang, et al. (2022), and consists of the following steps. First, we set the full range of samples to be donated by T, and the rolling sample length is l. We obtain a set rolling window, in which each small part is expressed as l, l+1, ... T and T-l+1, and we can also calculate the subsamples. Therefore, we rely on the application of *RB*-based modified-*LR* statistics to obtain the subsample Granger-causality results. The causality changes between the GBI and COP are determined by the p-values of *LR* statistics observed through subsamples in rolling windows. The causality between COP and the GBI is shown by the average of all bootstrap estimates $N_b^{-1}\sum_{k=1}^{p}\widehat{\beta}^*_{12,k}$, the influence of the GBI on COP is represented by $N_b^{-1}\sum_{k=1}^{p}\widehat{\beta}^*_{21,k}$, and N_b represents the number of boot straps. $\widehat{\beta}^*_{12,k}$ and $\widehat{\beta}^*_{21,k}$ represent the values of the estimated parameters obtained from the VAR system.

5. Data source and descriptive analysis

This article examines the causal relationship between COP and green bonds and then explores whether COP has a definite influence on expectations in the green bond market, using monthly data covering the period January 2011 to July 2022. Because of economic progress, crude oil has a firm position in the structure of global energy and makes up a large proportion to overall energy consumption. Unfortunately, burning crude oil releases many pollutants that harm the environment, such as GHGs, which lead to global warming. The Chinese government has taken some effective measures to support renewable energy projects, resulting in a boom in green projects (Kyritsis & Serletis, 2019; Xia et al., 2019). Green bonds are viewed as an instrument of financing, and the bond market faces "green bond prosperity" (Zhou & Cui, 2019). Naeem et al. (2021) confirm that green bonds are regarded as an attractive financial vehicle because they hedge the risks of market prices for commodities. We use the S&P index to measure the development of green bonds (Park et al., 2020), available at https://www.spglobal.com. At the same time, we use the price of West Texas Intermediate oil to proxy for COP (Chiroma et al., 2015), with the data from the Wind database. The US dollar index (USD) demonstrates the volatility in the value of the US dollar and is the currency quoted in global oil market, so we use it as a control variable (Kocaarslan, 2021), also with data from the Wind database.

The trends in the GBI and COP are shown in Fig. 1. Global economic conditions start to recover since 2011, leading to an increase in COP. A series of political crises since 2014, such as regional conflict between Russia and Ukraine, resulted in a sharp decrease in COP. Influenced by a further decline in prices, countries that produce crude oil face depreciation, which contributes to the decline in COP, creating a vicious circle. The global green bond market has made gradual progress since 2013, and annual issuance increased from US$11 billion in 2013 to US$42.5 billion in 2015. In 2013 and 2014, participation in the issuance of green bonds expanded to additional private enterprises, such as firms and merchant banks. But, in 2014, the impact of the low COP led to a decrease in investor demand for green bonds, and the GBI fell. In 2015, shale oil production continued to grow in the US, Saudi Arabia maintained a high volume of oil production, and Iran signed a protocol about nuclear energy. These events led to further oversupply in crude oil and decreases in COP. At the same time, divesting from fossil fuels and providing financial support for creating a climate-resilient economy has become more important. Investor interest in financial opportunities from green projects has been stimulated by the 2015 Paris Climate Agreement. Various issuers and investors show great interest in the green bond market, leading to growth in the green bond market and increases in the GBI. In 2018, the US-China trade war had a notable impact on growth in the global economy, and COP and the GBI both trended downward. The impact of the COVID-19 pandemic and Russo–Saudi oil war drove COP down and affected the green bond market, which caused a slight decrease in the GBI in early 2020. Hence, the two variables have a complex and time-varying causal relationship. Further, COP and the GBI are denominated in the US dollar, whose value affects the two markets. For example, a rise or fall in the US dollar leads to an equivalent change in the GBI and COP.

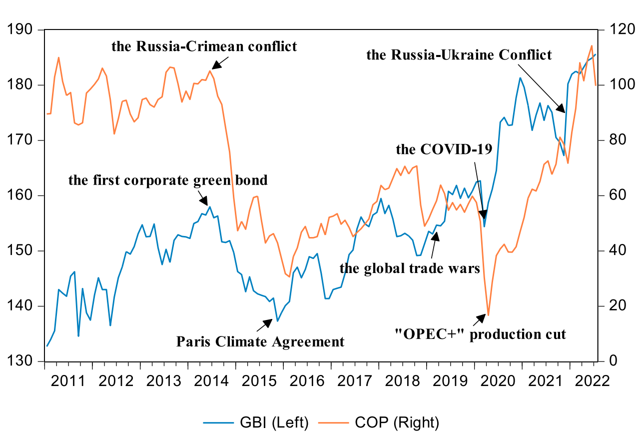

Fig. 1. The trends of GBI and COP.

The descriptive statistics are shown in Table 1. The average GBI, COP, and USD values reflect that their series is concentrated at the 146.822, 66.177, and 108.670, respectively. We infer that the GBI and COP have a right-skewed distribution, but USD has a left-skewed distribution. The results of the Jarque-Bera test indicate that COP and the GBI have a significant nonnormal distribution at the 5 percent level, even though USD distribution at the 1 percent level. Thus, there is no rational reason to use the traditional Granger-causality test. So, we use a bootstrap subsample rolling-window test to examine the Granger-causal relationship between COP and GBI. In order to avoid potential heteroskedasticity in the GBI, COP, and the USD, we take natural logarithms of the three variables. Further, we solve their nonstationarity problems by taking first differences for these three variables.

6. Empirical results

6.1. Time-varying analysis

Based on Equation (9), we can explore the full-sample causality of the GBI and COP by constructing a bivariate

Table 1
Descriptive statistics.

	Max.	Min.	Mean	Skewness	Kurtosis	Jarque-Bera
COP	114.285	16.699	66.177	0.399	2.044	7.831**
GBI	185.641	112.611	146.822	0.005	1.872	6.411**
USD	123.300	90.760	108.670	0.784	2.220	15.464***

Note: ** denotes significance at 5% level.

Table 2
Full-sample Granger causality tests.

	H_0: COP does not Granger cause GBI		H_0: GBI does not Granger cause COP	
	Statistics	*p*-values	Statistics	*p*-values
Bootstrap *LR* test	0.528	0.833	1.401	0.205

Vector autoregression (VAR) model. Based on the Schwarz Information Criterion (SIC), the optimal lag length is 1. Table 2 lists the empirical outcomes. There is no evidence that COP Granger causes the GBI or vice versa because all the *p*-values are insignificant. However, these consequences are the opposite of the previous conclusions and the relevant model for green bonds and oil prices.

Because of the fixed parameter values and the VAR model assumption of a full sample in the estimation period, we find only unidirectional causality between the GBI and COP over the full time series. But the causal relationship between the GBI and COP is unstable because of the parameter's variation and structural breaks. The characteristic can be examined with *Exp-F*, *Sup-F,* and *Ave-F* tests (Andrews, 1993; Andrews & Ploberger, 1994). The relevant outcomes are shown in Table 3.

The findings on the GBI and COP are presented in Table 3. The consequences of the *Sup-F* test show sharp breaks at the 1 percent level. The result of the *Ave-F* test indicates that the parameters vary over time at the 1 percent level. The *Exp-F* test reports that the time-varying parameters are at the same level. The results of the unidirectional causal relationship are unreliable because of the inconsistant parameter. Hence, we consider the time-varying parameters between subsamples when a rolling window is used to examine the causal relation between the GBI and COP in a modified-*LR* causality experiment in accordance with *RB.* Based on the *RB*-based modified-*LR* causal relation experiments, we confirm the null hypothesis that the GBI has no impact on COP and vice versa. The VAR model identifies the bootstrap *p*-values. The accuracy and robustness of the test results depend on a suitable rolling-window width. In general, if the window size is too large, the number of subsamples and the representativeness of the parameters would be reduced. And if it is too small, these problems would be solved, but the variance of each estimate could increase. Therefore, it is necessary to make a compromise in the window size. Following Balcilar et al. (2010), we therefore select a width of 24 months to guarantee accuracy.

Table 3
Parameter stability test.

	COP Equation		GBI Equation	
	Statistics	*p*-value	Statistics	*p*-value
Sup-F	22.788***	0.001	50.044***	0.000
Ave-F	6.737**	0.031	16.972***	0.000
Exp-F	8.089***	0.002	20.738***	0.000

Notes: We calculate *p*-values using 10,000 bootstrap repetitions. *** and ** denotes significance at the 1% and 5% levels, respectively.

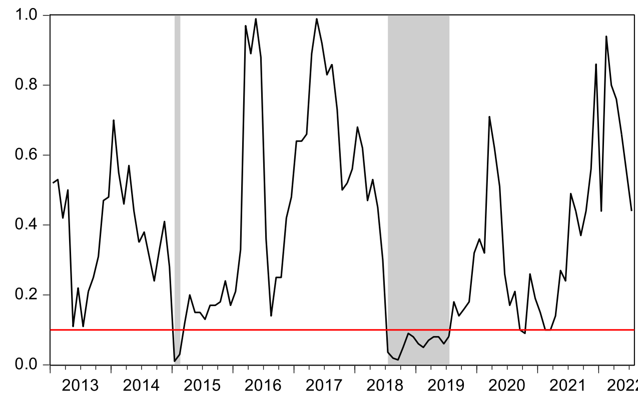

Fig. 2. The *p*-values for the hypothesis that COP does not Granger cause GBI.

Figs. 2 and 3 display the bootstrap *p*-values and the direction of the effect from COP to the GBI. At a significance level of 10 percent, COP Granger causes the GBI in the periods January–May 2015 and July 2018–July 2019. The effect of COP on the GBI is positive from January to February 2015, but negative from July 2018 to July 2019.

The positive effects demonstrate that COP has an impact on green bond prospects. Demand for oil has decreased since 2014 because of the slowdown in the world economy, and, in addition to the excess supply of oil, the price of oil has plummeted dramatically. At the beginning of 2015, COP fell significantly, after some regular fluctuations. The decline in COP has influenced thriving green projects (Banga, 2019). From a cost-benefit perspective, environmentally friendly projects have higher building expenses than those reliant on the price of oil, so it is challenging to develop clean energy (Ferrer et al., 2018). As a result, any significant reduction in COP will reduce the attractiveness and economic viability of green projects and lead to a sudden end to their development, negatively affecting the GBI. This supports the positive effects of COP on green investment during the period January to February 2015.

The negative impacts do not demonstrate that green bonds are valuable instruments for reducing the danger of COP shocks, and COP and the GBI show the same trend over two

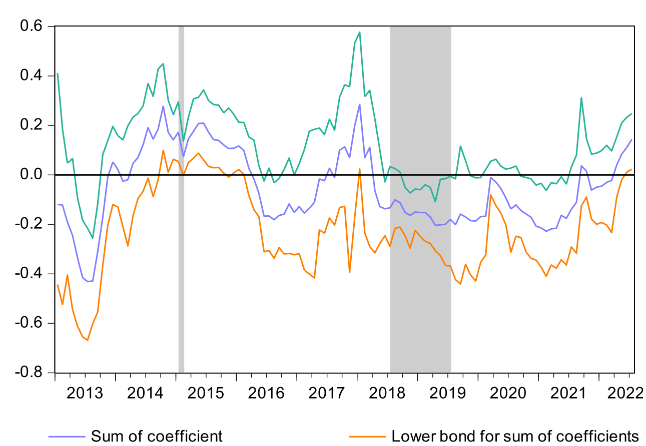

Fig. 3. The Coefficients for the influence from COP to GBI.

periods. In 2018, the US became the world's top oil producer, after shale oil production there reached record levels. The Organization of Petroleum Exporting Countries (OPEC) is no longer the sole source of oil exports. The implementation of a broader agreement among OPEC members to limit production did not prevent the growth of American shale oil output. As a result, COP fell, and excessive supplies of oil accumulated (Khan et al., 2020).

The surplus led to a drop in COP, which discouraged investors in the sector. Investors who want to support the energy transition and environmental protection gained interest in green bonds. They invest in green bonds in order to participate in green development, not only to obtain high yields (Ferrer et al., 2021). Additionally, whereas renewable energy is used mainly for electricity production, oil is predominantly employed in transportation and production (Dutta, Bouri, et al., 2020). Therefore, they are not direct alternatives, and a decline in COP may have a beneficial effect on demand for green investment (Hu et al., 2022). Renewable energy production methods continuously develop because of technological advancements, which reduce production costs (Ferrer et al., 2018).

Additionally, this attracts additional money to green investment, raising the GBI. Green energy companies make more money as a result of more practical financing options for projects using renewable energy sources and ongoing operating cost reductions. This also prevents the value of green bonds from fluctuating as oil prices do. Thus, it is possible to demonstrate that COP had a detrimental impact on the GBI between July 2018 and November 2018. The deal between OPEC and Russia to restrict production in 2019 went into force in January. With the help of a reduction in OPEC's output and the US exemption from sanctions against Iran, which expired in May, the surplus was significantly reduced. Moreover, the increase in shale oil production in the US was also smaller than anticipated. The consequences of all these factors together caused COP to climb in 2019. According to statistics from the Climate Bonds Initiative (CBI), US$257.7 billion worth of green bonds was issued globally in 2019. But in 2019, unilateralism, protectionism, and populism went increasingly out of control, creating several new negative scenarios and issues (Paul, 2021). The global economy is becoming more volatile and riskier because of rising trade conflicts and geopolitical concerns (Cunado et al., 2020). Investment in green bonds is declining due to general sluggishness in the world's major economies. Therefore, we agree that COP may have adversely affected the GBI from December 2018 to July 2019.

Figs. 4 and 5 illustrate the causal relationship between the GBI and COP and its characteristics. When the significance level is 10 percent, we reject the null hypothesis that the GBI had no impact on COP from January to September 2013 and August 2019 to January 2021. In both periods, that the relationship between the GBI and COP is positive.

The positive impact of the GBI on COP shows that it is not feasible to use green bonds as an effective way to reduce the oil crisis for the following reasons. The Climate Bond Initiative Report states that the scale of green bonds issued globally in 2013 was US$11 billion. These data reflect the strong development potential of the green bond market, and the GBI increases accordingly. Nevertheless, the world is now in economic recovery, so demand for oil is likely to continue to increase (Hammoudeh et al., 2010). In addition, in the context of implementing quantitative easing and other policies, the value of the US dollar has tended to fall (Su et al., 2021). As a result, all these factors contributed to the high COP during this period. Despite their rapid growth, green bonds comprise a small portion of the bond market (Sartzetakis, 2021). Indeed, development of the green bond market will not reduce dependence on oil, nor will it lower COP. This confirms the GBI's positive influence on COP from January to September 2013.

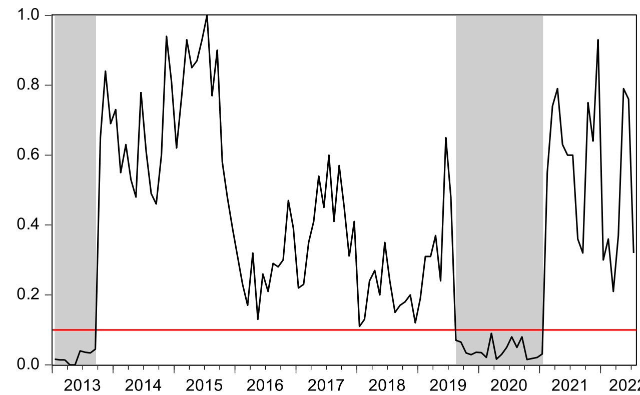

Fig. 4. The *p*-values for the hypothesis that GBI does not Granger cause COP.

From August 2019 to January 2021, COP might have been positively affected by the GBI. We explain it in two periods. In the second half of 2019, the green bond market was negative affected by antiglobalization and a stagnant global economy, and the GBI fell. At the same time, COP decreased because of appreciation of the USD and doubts in the market about OPEC's ability to cut production. Furthermore, the sharp rise in crude oil inventory in the US caused a decline in COP. At the beginning of 2020, the outbreak of COVID-19 had a severe impact on the entire financial market. These liquidity risks caused extreme downside risk for asset prices. The green bond

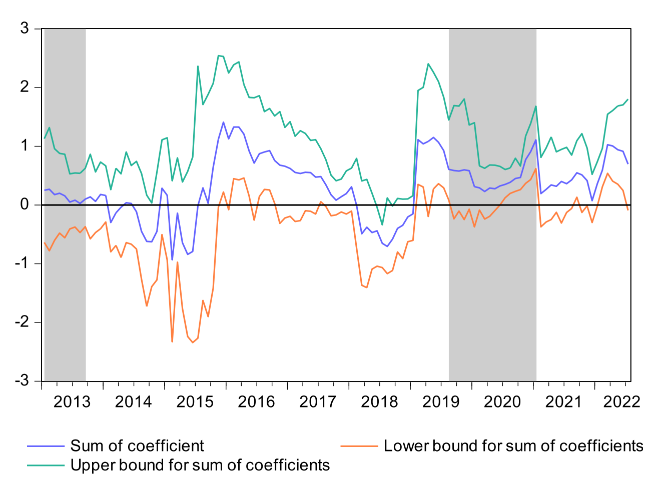

Fig. 5. The Coefficients for the influence from GBI to COP.

market was also affected by the pandemic, which hindered its prosperity and development, and the GBI declined. The pandemic significantly has significantly affected the oil market; many industries shut down, and demand for oil declined, leading to a fall in COP. The decline in COP was also driven by the OPEC crash and the signing of Russia's production reduction agreement. Therefore, the period August 2019 to April 2020 demonstrates that the GBI has a positive influence on COP. After the mid-twentieth century, the innovative reform of green bonds is employed to fight against the pandemic. Nevertheless, the economic recovery exacerbated the declines in demand for oil and COP (Wang & Zhang, 2021). The measures taken by the OPEC alliance to shrink the excess oil supply by reducing production also increased COP. Therefore, the positive influence of the GBI on COP is seen in the period May 2020 to January 2021. This shows that green bonds cannot be regarded as a tool for dealing with the oil crisis.

In summary, robustness and accuracy cannot be adequately guaranteed based on the traditional causal-relationship test, which can only examine unidirectional causality. Further, based on our analysis of the empirical results, the parameters in the model are unevenly reflected. Thus the bootstrap subsample rolling-window causality method explores the connection between the GBI and COP. The consequences yield limited evidence to demonstrate that high COP has the power to explain the increase in green bonds. Because of the positive influence, green bonds can be considered assets that neutralize the impact of COP. Meanwhile, oil and green bonds can be seen as equivalent because COP rises when the value of green bonds rises. However, because of the high-return rate in the green energy industry and the glut in the oil market, this view does not show a negative influence. Based on these results, which are consistent with the supply-and-demand–determined interaction mechanism of oil prices and green bonds, we find that COP influences the GBI, but not its direction. However, the GBI has a positive influence on COP. COP rises with increases in the GBI, as changes due to the COVID-19 pandemic, events in the Middle East, and the low scale of green bonds vary. Hence, we fail to find enough evidence that green bonds can effectively counteract an oil emergency such as oil disrupt.

6.2. Quantile-varying analysis

Next, we conduct the quantile Granger causality (QGC) test proposed by Troster (2018) to investigate the tail dependence between COP and the GBI in a conditional distribution. The precondition is that the variables need to be stationary. If this assumption is met, the null hypothesis of no Granger causality from X_t to Y_t in different quantiles can be described as follows:

$$H_0^{QC:X\nRightarrow Y}: Q_\tau^{Y,X}\left(Y_t\middle|\mathbb{I}_t^Y,\mathbb{I}_t^X\right)=Q_\tau^{Y}\left(Y_t\middle|\mathbb{I}_t^Y\right) \tag{10}$$

where τ is a compact set and in the range [0, 1]. $\mathbb{I}_t$ is the explanatory vector, $\mathbb{I}_t^Y = (Y_{t-1},\dots,Y_{t-s})' \in \mathbb{R}^s$, and $\mathbb{I}_t^X = (X_{t-1},\dots,X_{t-q})' \in \mathbb{R}^q$. When the τ conditional quantile $Q_\tau^Y(\cdot|\mathbb{I}_t^Y)$ is correctly specified by a parametric model $m(\mathbb{I}_t^Y, \theta_0(\tau))$, Equation (11) can be expressed as follows:

Table 4
Unit root test.

	ADF		PP		KPSS	
	level	Difference	Level	Difference	Level	Difference
COP	−1.742	−8.243***	−1.432	−8.069***	0.388*	0.225
GBI	0.359	−8.368***	0.342	−8.368***	1.288***	0.091

Note: *** and * denote significance 1% and 10% levels, respectively.

$$H_0^{QC:X\nRightarrow Y}: E\left[\Lambda\left(Y_t\le m\left(\mathbb{I}_t^Y,\theta_0(\tau)\right)\middle|\mathbb{I}_t^Y,\mathbb{I}_t^X\right)\right]=\tau, \forall\tau\in[0,1] \tag{11}$$

where $\Lambda[\cdot]$ is an indicator function. Subsequently, the statistics of the quantile Granger-causality test can be calculated as follows:

$$v_\tau(\omega,\tau)=\frac{1}{\sqrt{T}}\sum_{t=1}^{T}\Lambda\left(Y_t-m\left(\mathbb{I}_t^Y,\hat{\theta}_0(\tau)\right)\le 0-\tau\right)\exp(i\omega'\mathbb{I}_t) \tag{12}$$

where $\hat{\theta}_0$ is the estimation of θ_0. $i=\sqrt{-1}$ is the imaginary root. $\exp(i\omega'\mathbb{I}_t)$ denotes a weight function. $v_\tau(\omega,\tau)$ is defined as the quantile marked-residual process, indexed as $\omega\in\mathbb{R}$ and $\tau\in[0,1]$. Thus, the test statistic (S_T) is expressed as follows:

$$S_T=\frac{1}{T_n}\sum_{j=1}^{n}\left|\psi'_{\cdot j}W\psi_{\cdot j}\right| \tag{13}$$

where W is a $T\times T$ matrix with $w_{t,s} = \exp[-0.5(\mathbb{I}_t-\mathbb{I}_s)^2]$. $\psi_{\cdot j}$ denotes the jth column of Ψ. Ψ is the $T\times n$ matrix with the elements $\psi_{i,j} = \Psi_{\tau j}(Y_i - m(\mathbb{I}_i^Y, \theta_T(\tau_j)))$. $\Psi_{\tau j}(\cdot)$ is the function $\Psi_{\tau j}(\varepsilon) = \Lambda(\varepsilon\le 0)-\tau_j$. For statistics with large values, the null hypothesis can be rejected.

As shown by Troster (2018) and Troster et al. (2018), the stationarity of variables is the basic foundation of the QGC test. Thus, the paper conducts the ADF (Dickey & Fuller, 1981), PP (Phillips & Perron, 1988), and KPSS (Kwiatkowski et al., 1992) unit-root tests. Table 4 shows that the variables of COP and the GBI are not stationary at level but become stationary when at the first difference.

We next conduct the S_T test to check Granger causality between ΔCOP and ΔGBI under different quantiles, and the corresponding p-values are shown in Table 5. The fluctuations in the GBI do not Granger cause COP at the 1 percent, 5 percent, and 10 percent significance levels, considering all

Table 5
Quantile Granger causality test.

	$\Delta COP\nRightarrow\Delta GBI$			$\Delta GBI\nRightarrow\Delta COP$		
	Lag = 1	Lag = 2	Lag = 3	Lag = 1	Lag = 2	Lag = 3
[0.1, 0.9]	0.165	0.186	0.277	0.201	0.295	0.722
0.2	0.113	0.291	0.662	0.361	0.263	0.157
0.3	0.339	0.158	0.243	0.444	0.379	0.301
0.4	0.194	0.152	0.226	0.323	0.374	0.772
0.5	0.127	0.144	0.268	0.608	0.616	0.752
0.6	0.151	0.202	0.119	0.551	0.590	0.437
0.7	0.003***	0.001***	0.005***	0.333	0.568	0.521
0.8	0.009***	0.004***	0.011**	0.445	0.507	0.678
0.9	0.013**	0.008***	0.104	0.390	0.417	0.505

Note: Δ denotes log-difference. *** and ** indicate significance at 1% and 5% levels, respectively.

quantiles of the distribution. The potential reasons can be summarized as follows. First, the green bond market is not mature, and it has only domestic influence. In China, at the end of the second quarter of 2022, new issuance of green bonds totaled RMB 400.636 billion, which comprises 8.5 percent of bonds, and 1.91 percent of total financing. The low amount is not powerful enough to affect the international oil market. Second, oil suppliers hold the power over pricing (Wang et al., 2021). For example, China is the largest importer of crude oil, at 512.98 million tons, for US$255.33 billion in 2021. However, because oil suppliers can tacitly align their prices, it can only react to fluctuations in the oil price.

At the same time, COP Granger causes the GBI at the extreme tails of the distribution. Specifically, at the extreme tails of the conditional distribution, $\tau = 0.7$, 0.8, and 0.9, which indicates a Granger-causal link from COP to the GBI at the 1 percent and 5 percent significance levels, respectively. This asymmetric impact from COP to the GBI can be explained as follows. First, because they lack price power and have a mismatch between oil supply and demand, oil-importing countries are vulnerable to high oil price volatility (Liu et al., 2020). Oil is an important raw material, which directly increases production costs (Ren et al., 2022). In addition, the oil price can lead to inflation, with higher wages and transportation costs, which indirectly raise production costs (Chen et al., 2020). The increasing burdens drive people and firms to conserve energy and finance projects through issuing green bonds. Second, environmental problems, arising from the use of oil, become more severe with higher oil prices. A high oil price reduces firm's profits and people's wealth, which further limits the inputs for controlling pollution (Jia et al., 2021). Moreover, countries all over the world have achieved a consensus about reducing carbon emissions, and China has proposed a carbon peak and neutralization. Thus, the urgent environmental issues force the government and firms to take more social responsibility and reduce emissions through optimizing process and updating technologies. That inevitably increases demand for financing with green bonds.

7. Conclusions

In this research, we explore whether COP has an impact on the outlook for green bonds by testing the causality of the GBI and COP. By ignoring the instability in the parameters, our full-sample experiment indicates that the GBI and COP have no causal relation. So, we conduct a subsample test, which shows correlation in some specific periods. Based on this positive influence, we find that COP can influence the outlook for the green bond market and growth of the GBI as COP increases. However, because of the oil market glut, the negative influence does not demonstrate this dynamic in all periods. We can identify the impact of COP on the GBI but not the direction from the results of the supply-and-demand–determined interaction model of oil prices and green bonds. However, green bonds might not be regarded as effective ways to mitigate the oil price based on the positive impact between the GBI and COP since 2021, and changes in the green bond market have varied.

Our study has some significant implications. Green bonds have grown quickly in global financial markets, leading to more diversified issuers, investors, and investment projects. The market prospects demonstrate both opportunities and challenges. On the one hand, based on COP, the green bond market benefits the decisions of participants. To diversify their energy sources, these issuers of green bonds, such as oil-importing countries, can issue this bond at a large scale to overcome this change when COP rises. Green bonds are often regarded as a useful instrument for hedging fluctuating COP. To adapt to the market environment, investors can make strategic decisions to select green bonds to diversify their portfolio. Moreover, green bonds are the basic asset in the green financial market and leads to the creation of other financial products, stimulating interest from different kinds of financiers. On the other hand, investors have limited understanding of green investment because of the low volume in the green bond market. Therefore, it becomes important to take effective measures to promote evolution in the green bond market. For instance, it is important to accelerate the application of interest discounts and standardize issuance rules to trigger development of green bond market.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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