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Can the green bond market enter a new era under the fluctuation of oil price?

Chi Wei Su[a], Yingfeng Chen[a], Jinyan Hu[a,b], Tsangyao Chang[c] and Muhammad Umar[a]

[a]School of Economics, Qingdao University, Qingdao, China; [b]School of Economics, Shandong University, Jinan, China; [c]Department of Finance, Feng Chia University, Taichung, Taiwan

ABSTRACT

This paper investigates how oil price (OP) influences the prospects of green bonds by utilising the quantile-onquantile (QQ) method and researching the interactions between OP and green bond index (GBI) from 2011:M1 to 2021:M11. We find that impacts from OP on the GBI are positive in the short run. The positive effects indicate that high OP can promote the development of the green bond market, indicating that green bonds can be considered an asset to avoid OP shocks. However, in the medium and long term, there is a negative impact due to the oversupply of the oil market and the increase in green energy industry profits. These results are identical to the supply and demand-based correlation model of green bonds and oil price, which underlines a specific effect of OP on GBI. The GBI effect on OP is consistently positive across all quantiles. It indicates that green bonds cannot be considered efficient measures to alleviate the oil crisis due to the instability of the Middle East COVID-19 and the small scale of green bonds. The issuers of green bonds can make decisions based on OP. Understanding the relationship between OP and GBI is also beneficial for investors.

Abbreviations: OP: Oil price; QQ: Quantile-on-quantile; GBI: Green bond index; GHGs: Green House Gases; DWT: Discrete wavelet transform; MODWT: Maximal overlap discrete wavelet transform; CBI: Climate Bonds Initiative; WTI: West Texas Intermediate; EIB: European Investment Bank; IFC: International Finance Corporation; OPEC: Organization of Petroleum Exporting Countries; COVID-19: Coronavirus disease 2019

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1. Introduction

This paper ascertains whether OP can affect the prospects of green bonds. Energy is the economy's lifeblood; whether it is to maintain stable economic growth or ensure national security, a steady energy supply is required (Sivaram & Saha, 2018). As the

CONTACT Muhammad Umar umar@qdu.edu.cn

"blood of industry", oil plays an extremely vital role in promoting economic growth (Chimhowu et al., 2019). But in fact, oil resources are limited and unevenly distributed, mainly in politically unstable countries (Scholten, 2018). In competing for oil between countries, many international conflicts have been triggered, resulting in energy security issues (Colgan, 2013). Fossil fuels are not only in short supply but also face environmental problems. The burning of fossil fuels emits Green House Gases (GHGs) that contribute to climate change and global warming (Bondia et al., 2016). The world's energy demand continues to grow with the increase of the population, and countries worldwide have increased the emphasis on energy reforms (Su et al., 2021b). Governments need to strongly support green energy systems and invest heavily in renewable energy projects. It is also indispensable to accelerate the progress of the new energy vehicle industry to reduce the demand for internal combustion engine vehicles, thereby reducing the dependence on oil (Sachs et al., 2019). However, these measures require a lot of financial support; due to the low yield and particular risks of green projects, the private sector has little interest in making long-term investments in them (Yoshino et al., 2019). Therefore, the world urgently needs to create a financial product to raise funds and accelerate the process of low-carbon development (Kaggwa et al., 2013; Tao et al., 2022). Green bonds are a product that raises funds for green projects and promotes sustainable development (Ji et al., 2021a; 2021b; World Bank 2019). When OP is constantly fluctuating, finding alternative energy sources is crucial (Buyukozkan & Guleryuz, 2016). Since most of the funds raised by green bonds are used to construct renewable energy projects, the high OP inevitably encourages renewable energy investment, thereby promoting the issuance and acquisition of green bonds (Tolliver et al., 2020). In addition, green bonds provide financial support for the energy transition as a financing tool and give the investors more diversified investment strategies as a hedging asset. (Le et al., 2021). Since the subprime mortgage crisis in 2008, OP has been extremely unstable, and the volatility of OP as a risk has been detrimental to financial markets (Umar et al., 2021d; Zhang, 2017). An increase in OP is often accompanied by inflation (Salisu et al., 2017), which reduces real returns and reduces investor confidence (Shahzad et al., 2019), so there are needed to hold the hedging assets (e.g., green bonds) to obtain diversification benefits (Bildirici & Badur, 2019; Elfayoumi, 2018; Naqvi et al., 2021; Su et al., 2020c). Therefore, in changing oil prices at different times, knowing whether green bonds are hedging can help investors optimise their investments. (Ferrer et al., 2021; Karim et al., 2022; Umar et al., 2021c).

GHGs emissions are a problem wherever fossil fuels are burnt to produce energy (Rafieisakhaei & Barazandeh, 2017). Since climate change is very harmful, if the current status of fossil fuel use is not controlled, it will pose a significant threat to human society and the ecological environment. (Sachs & Du Toit, 2015). To accelerate the transition to a climate-based economy, investment in fossil fuels needs to be reduced while green energy projects need to be increased (Hasnaoui et al., 2021; Kaiser & Welters, 2019; Kaminker, 2015; Yu et al., 2022). This is a boon for issuers and investors of green bonds, providing them with new financial opportunities. Issuers can raise enough funds to support green energy projects, and investors can get fixed returns by earning interest (Jin et al., 2020). With the emergence of environmental pollution and energy security, green bonds have begun to develop as an innovation in sustainable finance. High OP impacts the prospects of green bonds by stimulating investor enthusiasm and incentivising issuers to continue issuing. The use of fossil fuels is accompanied by resource depletion and air pollution. Because renewable energy is a substitute for crude oil (Fu & Ng, 2021), renewable energy development under high oil prices has become a consensus of the international community (Brini et al., 2017; Yuan et al., 2022). Shah et al. (2018) study the implications of OP for renewable energy investment and found a positive and noticeable effect in the US. In order to satisfy the fast-growing energy demand and respond to the shocks of OP, two-thirds of green bonds issued in the Association of Southeast Asian Nations countries are used to fund renewable energy and energy efficiency projects. The EU issues green bonds to provide financial support to the green transition. The multilateral development bank issues green bonds primarily to fund renewable energy projects (BNEF, 2014). To fund investments in renewable energy, the world's largest aluminium recycler is also issuing green bonds in 2021. According to the Climate Bonds Initiative (CBI), annual green bond issuance could reach USD 1 trillion by 2023. Green bonds have a lot of potential for growth. The US is the largest issuer of green bonds, and countries such as France, Germany and the Netherlands have issued their own green bonds. This paper examines whether OP will stimulate the green bond market. The investigation could be critical for the investors and issuers of green bonds. Issuers can make decisions based on OP, and investors can comprehend the effect of OP on environmental investments and build optimal investment portfolios to diversify risks.

This paper has several marginal contributions. Firstly, in the financial market, participants are increasingly aware that energy reform policies will be affected by environmental pollution and energy crises (Tolliver et al., 2020). Green bonds, as a green financial tool aimed at promoting energy transition and addressing climate change, have received more attention. (Clapp & Pillay, 2017; Reboredo, 2018). Since the relationship between OP and GBI can indicate how the green bond market responds to OP fluctuations, investors who understand the relationship can shift funds to green bond investments in the face of risks brought by the rising OP, thereby avoiding risks and improving returns. Therefore, knowledge of the interaction is helpful for investors. Secondly, it is also essential for issuers to know the interaction of OP and GBI, especially the major oil-importing and exporting countries. They can decide the issue scale of green bonds according to the fluctuation of OP and improve energy self-sufficiency and energy security by enriching the variety of energy resources. Finally, in contrast to previous work, we strive to identify the causality between OP and GBI. This paper improves the existing literature by applying a method combining the QQ method and wavelet transform to study the impact of OP on GBI further. This checks for nonlinear relationships of variables in different quantiles. The empirical outcomes are supported by the supply and demand-based correlation model of green bonds and oil price, which shows the specific influences from OP to GBI. OP can influence the prospects of green bonds, and the increases in OP can accelerate the growth of the green bond market. The positive effects of GBI on OP prove that green bonds cannot be considered efficient measures to alleviate the oil crisis. This signals to the market that the green bonds still have great potential for development, and governments need to take adequate measures to promote this process.

The rest of this paper is arranged as follows: Section 2 lists the literature related to this paper. Section 3 introduces a related theoretical model called the supply and demand-based correlation model of green bonds and oil price. Section 4 focuses on introducing the relevant methodology. Section 5 presents the appropriate data. Section 6 analyses the empirical results. Section 7 is the conclusion and economic implications.

2. Literature review

Much literature supports the idea that green bonds can be affected by the OP. Green bonds are mainly used to support renewable energy and green transportation projects, which significantly impact environmental protection and pollution reduction (Trompeter, 2017). Broadstock and Cheng (2019) claim that lessened OP increases oil demands and reduces the incentives for social responsibility investment. Lee et al. (2021) find that OP can forecast the green bond price. Bondia et al. (2016) find that a surge in OP encourages green investments. The rise in OP will stimulate consumers and investors to seek cheaper alternatives, making green energy more competitive, thereby promoting the development of green projects (Managi & Okimoto, 2013). For oil-importing countries, if the oil used in economic life is heavily dependent on import, it will reduce the resilience of the economy and make the economy more vulnerable to OP fluctuations (Barsky & Kilian, 2004; Hamilton, 1983; Taghizadeh-Hesary et al., 2016; Taghizadeh-Hesary & Yoshino, 2016). In general, an increase in OP disrupts its economic growth and brings inflation (Taghizadeh-Hesary et al., 2013). Oil-importing countries diversify their energy resources and further ensure energy security by issuing green bonds. Azhgaliyeva et al. (2021) demonstrate that the increase in OP may lead many economies, especially oil-importing countries, to accelerate the process of energy diversification, thereby increasing the issuance of green bonds. Conversely, the pressure to promote renewable energy progress will also be reduced due to the decline of OP; they may facilitate the distribution of green bonds and continue to rely on oil resources. For crude oil-exporting countries, the decrease in OP will also motivate them to issue green bonds to accelerate the development of renewable energy and thus diversify their economies. In addition, the oil warfare between Russia and Saudi Arabia threatens the growth of green projects due to the fall of OP. The COVID-19 outbreak and the economic downturn have led to a sharp decline in OP, and the lower OP is not conducive to developing green bonds. This reduces investor appetite for renewable technologies and puts the Paris Climate Agreement at risk (Mirza et al., 2020a; 2020b; 2020c; Taghizadeh-Hesary et al., 2021). Crude oil is a significant strategic resource, and drastic price fluctuations will impact the global economy (Gu & Zhang, 2016; Yuan et al., 2014). Yan et al. (2022) believe that changes in OP are often indicative of changes in the economy, and the government needs to reconsider strategies to promote green bond investment when oil prices are low. Azhgaliyeva et al. (2021) research the impact of oil price shocks on green bond issuance, and they find that oil supply shocks have a positive impact on green bond issuance. Understanding the linkages between green bonds and other assets can help investors build optimal portfolios (Hung, 2021; Su et al., 2020a; Umar et al., 2021a; 2021b). Lee et al. (2021) find that green bonds can be used as financial instruments to hedge against OP shocks. Kanamura (2020) finds that if green bonds also have value as environmental assets, it is estimated to be positively correlated with the value of crude oil.

However, the idea that OP affects the prospects of a green bond is not always supported. Green bonds are mainly used to support renewable energy development. Auran and Gullaksen (2017) noted no intense competition as renewable energy and oil are active in different markets. For example, oil is used in transportation and production sectors, while renewable energy is mainly used in power. Therefore, by not being direct substitutes, the demand for the green bond does not necessarily increase when the OP rises. The financing, capital and operating costs of renewable energy projects continue to decline, leading to the decoupling of green bonds from OP. The green bond market is still tiny compared to the global bond market and lacks generally accepted definitions and commonly acknowledged standards (Ehlers & Packer, 2017). There is heterogeneity among green bonds due to inconsistencies in definitions and standards. This leads to suspicion and limits the investment universe of ethical investors even though the OP shocks (Cowan, 2017). Reboredo et al. (2020) find that oil and green bond markets are weakly interconnected despite the time scales. Lee et al. (2021) find that OP has only a weak effect on GBI when the green bond market and oil market are bullish, and the trend of OP is not significant for green investment incentives. In addition, the oil consumption strategies cannot effectively predict the oil price during the period of expansion, neither the expansion strategies nor the contraction strategies can significantly affect the development of green projects, so from the perspective of energy policy, the correlation between green investment and the oil market is minimal. Therefore, this nonlinear transmission mechanism and asymmetric causality must be considered when making decisions for investors.

To sum up, there is no consensus on whether the changes in OP affect the prospects of green bonds. Therefore, this paper further researches the interrelationship between the oil and green bond markets to investigate whether OP shocks influence green bonds. Traditional vector autoregression and granger causality perform poorly in capturing the nonlinear features of links. Thus, we employ a wavelet-based quantile-to-quantile approach to identify effects of varying degrees. In addition, we can prove the effect of GBI to OP to examine whether green bonds can be considered efficient measures to alleviate the oil crisis.

3. The supply and demand-based correlation model of green bonds and oil price

The supply and demand-based correlation model of green bonds and oil price, developed by Kanamura (2020), can explore the interaction between GBI and OP. The equilibrium prices of the OP_t and GBI_t are as follows:

$$\mathrm{OP_t} = \left(1 + a_1 \frac{D_t}{c_1}\right)^{\frac{1}{a_1}} \tag{1}$$

$$\mathrm{GBI_t} = \left(1 + a_2 \frac{\overline{V}_t - V_t}{c_2}\right)^{\frac{1}{a_2}} \tag{2}$$

$$\mathrm{dD_t} = \mu_D \mathrm{dt} + \sigma_D \mathrm{dw_t} \tag{3}$$

$$\mathrm{dV_t} = \alpha(\mathrm{OP_t})\mathrm{dD_t} + \sigma_V \mathrm{dz_t} \tag{4}$$

where OP_t is given in Equation (1) and the volume D_t process corresponds to demand in Equation (3) under short-run price inelasticity of demand. GBI_t is given in Equation (2) and the volume V_t process corresponds to supply in Equation (4) under short-run green bond price inelasticity of supply (Kanamura, 2012;; 2015). $\overline{V}_t$ is a constant value, and the upper limit of V_t. Kanamura (2015) believes that the V_t goes in the same direction as trading volume. Kanamura (2020) assumes that OP impact the volume processes of the GBI using $\alpha(OP_t)$ in Equation (4) to research the effects of OP on GBI.

Note that $E_t[dw_t dz_t] = \rho dt$. By using Ito's Lemma, we have:

$$the\ \overline{\sigma}_{\mathrm{GBI}} = \sqrt{\alpha(\mathrm{OP_t})^2 \sigma_D^2 + \sigma_V^2 - 2\rho\alpha(\mathrm{OP_t})\sigma_D\sigma_V} \tag{5}$$

$$\begin{aligned} \rho_{OG} &\equiv \frac{1}{\mathrm{dt}} corr\left(\frac{\mathrm{dGBI_t}}{\mathrm{GBI_t}}, \frac{\mathrm{dOP_t}}{\mathrm{OP_t}}\right) \\ &= \frac{-\alpha(\mathrm{OP})\sigma_D + \rho\sigma_V}{\overline{\sigma}_{\mathrm{GBI}}} \end{aligned} \tag{6}$$

This is the supply and demand-based correlation model of green bonds and oil prices. Note that ρ_{OG} is positive when $-\alpha(OP)\sigma_D + \rho\sigma_V > 0$, and

$$\frac{\partial \rho_{OG}}{\partial \mathrm{O}P} = -\frac{\sigma_D \sigma_V^2}{\overline{\sigma}_{GBI}^3}\left(1 - \rho^2\right)\frac{\partial \alpha}{\partial \mathrm{O}P} \tag{7}$$

If $\frac{\partial \alpha}{\partial OP} < 0$ is shown; ρ_{OG} is an increasing function of OP. However, the correlation model suggests that OP has specific effects on GBI but cannot determine the direction.

Due to the increase in market volatility and spillover effects in the financial market under globalisation, the correlation between green bonds and traditional assets such as oil is becoming more critical. Green bonds are a particular financing vehicle with strict regulations on funds. They require funds for eligible green projects, including refinancing new projects (Broadstock & Cheng, 2019). With the rapid growth of green bonds, more funds are used to construct renewable energy (Tolliver et al., 2020). As a green alternative to traditional fossil energy, renewable energy has attracted extensive concern from investors (Buyukozkan & Guleryuz, 2016). In order to seek more fossil fuel substitutes, with the prosperity of the green energy industry, competition is more intense. The high OP prompts alternative effects from oil energy to replace energy. Therefore, the green energy industry will develop positively under the high OP; accordingly, the green bond market is gradually prospering (Ayres & Ayres, 2009). In addition, for consumers, high OP means spending more on energy consumption (Henriques & Sadorsky, 2011). Further, for producers, increasing OP is accompanied by a surge in cost and reduces the availability of critical inputs, decreasing the output (Brown & Yücel, 2002). It also encourages the development of the green bond market. Dutta et al. (2020a) pointed out that the incentives and benefits of green investments increase when the OP faces an upward trend, thereby increasing the value of green products such as green bonds. Conversely, investment incentives for green bonds decrease with negative volatility in the oil market (Bondia et al., 2016; Xia et al., 2019).

4. Methodology

4.1. Wavelet analysis

In applying economics methods, wavelet analysis is widespread (Su et al., 2019; 2020b; 2022a). It is characterised by a wave oscillation that starts from zero and changes back to zero (Yahya et al., 2019). The problem of fitting time series in the time and frequency domains can be solved by using wavelets of different frequencies (Crowley, 2007; Graps, 1995; Torrence & Webster, 1999). Next, the wavelet is constructed dyadically and converted to the following pair of specially constructed functions δ and γ:

$$\int \delta(\mathrm{t})\mathrm{dt} = 1 \tag{8}$$

$$\int \gamma(\mathrm{t})\mathrm{dt} = 0 \tag{9}$$

In the above function, δ represents the father wavelet and γ represents the mother wavelet. In the variables, δ can test the smooth and low-frequency sections and γ can test the comprehensive and high-frequency sections. Therefore, we can achieve the wavelet as follows:

$$\delta_{\mathrm{p,q}}(\mathrm{t}) = 2^{\frac{j}{2}}\delta(2^{\mathrm{p}}\mathrm{t} - \mathrm{q}) \tag{10}$$

$$\gamma_{\mathrm{p,q}}(\mathrm{t}) = 2^{\frac{j}{2}}\gamma(2^{\mathrm{p}}\mathrm{t} - \mathrm{q}) \tag{11}$$

The scrutiny can measure the number of scales, while the number of observations limits its maximum number ($T \geq 2^{p}$).

$\delta_{\mathrm{p,q}}(\mathrm{t})$ is the coefficient of the attribute positioning which is a particular attribute of the wavelet expansion. It can denote amount of information in the function such as the estimated position $q2^{-p}$ and frequency 2^p. Hence, at the random level $p_0 \in \mathbb{N}$, the $L^2(\mathbb{R})$ can extend underlying wavelet in diverse scales.

$$X(t) = \sum_q C_{po,q}\delta_{po,q}(t) + \sum_{p>po}\sum_q d_{p,q}\delta_{p,q}(X)\ldots\ldots\ldots\ldots p = p_0\ldots\ldots p \tag{12}$$

The above function, $\delta_{po,q}$ shows the scaling function and scale coefficient. $C_{po,q}$ denotes the comprehensive coefficient appointed by $C_{p0,q} = \int X(t)\delta_{j,k}(t)dt$, and $d_{p,q}$ denotes corresponding coefficient appointed by $d_{p,q} = \int X(t)\gamma(t)dt$. $C_{P,t} = \sum_q C_{p0,q}\delta_{po,q}(t)$ can detect low-frequency feature by providing a smooth form of the original series $X(t)$, and $X(t)$'s higher frequency feature can be tested by $D_{p,t} = \sum_k d_{p,q}\gamma_{p,q}(t)$.

4.2. Maximum overlap discrete wavelet transform

The discrete wavelet transform (DWT) is used to discrete sample, and then perform the wavelet transforms. The scale filter r (r l, l=0,… …. L–.1[2]) and wavelet filter ($s_l, l = 0, \ldots., L - 1$[3]) are basics. The length of the filter can be denoted by $L \in \mathbb{N}$ (Percival & Mofjeld, 1997). Also, the filters need to satisfy the following three characteristics.

$$\sum_{l-0}^{L-1} r_l = 0, \quad \sum_{l-0}^{L-1} r_l^2 = 0, \quad \sum_{l-0}^{L-1} r_l r_{l+2n} = 0 \forall \ n \in \mathbb{N} \tag{13}$$

Quadrature mirror filter can express the low and high pass filter:

$$r_l = (-1)^l s_{L-1-l} \text{or} \ s_l = (-1)^{l+1} r_{L-1-l} = l = 0\ldots., \ L-1 \tag{14}$$

In the same way, scaling filters satisfy the conditions.

$$\sum_{l=0}^{L-1} s_l = \sqrt{2}\sum_{l=0}^{L-1} s_l^2 = 1 \ \text{and} \ \sum_{l=0}^{L-1} s_l s_{l+2n} = 0 \ \forall \ n \in \mathbb{N} \tag{15}$$

In the pth level for $p\in\{1, \ldots, p\}$, the wavelet and scaling coefficient of DWT can be defined as:

$$\boldsymbol{h}_{j,t} = \sum_{l=0}^{L-1} r_l X_{t-1} \ \text{and} \ \boldsymbol{g}_{j,t} = \sum_{l=0}^{L-1} s_l X_{t-1} \tag{16}$$

The method of the maximal overlap discrete wavelet transform (MODWT) can decompose series and solve the limitation of DWT (Percival & Mofjeld, 1997). Because the wavelet has high ability to test time scale deviation of the series, scaling coefficient and daubechies least asymmetric can achieve it.

We can obtain a set of wavelet coefficients and different frequency bands by decomposing the primary data sequences. In addition, we can achieve the rescaled scaling through incorporate the MODWT:

$$\tilde{j}_{p,l} = \frac{r_{p,\ l}}{2^{\frac{p}{2}}} \text{ and } k_{p,l} = \frac{s_{p,\ l}}{2^{p/2}},\ p = 0, \ldots,\ p \tag{17}$$

According to the study of Mallat (1989), we can get the $\tilde{h}_{p,t}$ and $\tilde{g}_{p,t}$ through the pyramid algorithm. All iterations of the MODWT algorithm require three inputs. First, we should start with faltering data and then give wavelet and scaling coefficient.

$$\tilde{h}_{1,t} = \sum_{l-0}^{L-1} \tilde{r}_l X_{t-1} and\ \tilde{s}_{1,t} = \sum_{l-0}^{L-1} \tilde{s}_l X_{t-1} \tag{18}$$

The scaling coefficient can become the input data vector, and it is helpful to implement the second step. We can explain the second level wavelet:

$$\tilde{h}_{2,t} = \sum_{l-0}^{L-1} \tilde{r}_l \tilde{g}_{1,t-l} \text{ mod N and } \tilde{g}_{2,t} = \sum_{l-0}^{L-1} \tilde{s}_l X_{t-l} \text{ mod N} \tag{19}$$

In the same way, the scaling coefficient and the pth level MODWT wavelet of $X\ t$ can be signified as:

$$\tilde{g}_{J,t} = \sum_{l-0}^{L-1} \tilde{s}_l X_{t-l} \text{ mod N and } \tilde{h}_{p,t} = \sum_{l-0}^{L-1} \tilde{r}_l \tilde{g}_{1,t-l} \quad \text{mod N} \tag{20}$$

4.3. The quantile-on-quantile method

DWT has a dyadic length limit and is non-shift invariant for sequences to be transformed. Therefore, to deal with these shortcomings, we introduce MODWT. It can manage any sample size by giving up orthogonality and whether the sequence is dyadic or not (Haniff & Masih, 2018). MODWT can manage multivariate analysis, an advantage (Crowley & Lee, 2005). Also, on the whole, quantile regression suffers from a shortage of power capture dependence (Gupta et al., 2018). It ignores the low, normal or high nature of the OP and thus affects the analysis of the GBI. Quantile regression does not consider the nature of the size change that affects the association (Gao et al., 2021). There has an asymmetric relationship that a positive change on one variable could have a diverse effect on another variable than an unassessed negative shock. Therefore, the QQ method can make variables have varying correlations at different points of their respective distributions, thereby detecting overall dependencies. Therefore, the QQ method can make variables have inconsistent correlations at different points of their distributions, thereby detecting general dependencies. The QQ method can offer an overall perspective of dependence (Gupta et al., 2018). The QQ method is flexible and can prove the influences of different levels of shock and the structure of heterogonous tail dependence, so it can be used as a functional form for detecting dependencies among variables.

This paper shortly states the feature of the QQ approach suggested by Sim and Zhou (2015). Then, we explain the model to research the influence of OP on the

GBI. This approach is applied to find out the influence of the OP on GBI, and it is a sum of nonparametric estimation of local linear regression and quantile regression (Li & Yuan, 2021). Thus, we apply the QQ method to detect the effect of the quantiles of OP on the quantiles of the various GBI.

We start with a nonparametric quantile regression model:

$$\mathrm{GBI} = \alpha^{\vartheta}(\mathrm{OP_t}) + \varepsilon_{\mathrm{t}}^{\vartheta} \tag{21}$$

To research the causality between the ϑth quantile of OP^{τ}, we use local linear regression. The estimation of the function can be through a first-order Taylor expansion about the quantile OP^{τ} because of the unidentified $\alpha^{\vartheta}(.)$.

$$\alpha^{\vartheta}(OP_{t-1}) \ = \alpha^{\vartheta}(OP^{\tau}) \ + \ \alpha^{\acute{\vartheta}} \ (OP^{\tau}) \ (OP_{t-1} - OP^{\tau}) \tag{22}$$

α^{ϑ} denotes the partial derivative of $\alpha^{\vartheta}(\mathrm{OP_{t-1}})$ in the background of OP. The results are called marginal effects and can be interpreted as slope coefficients in a linear regression model.

There is an obvious aspect in Equation (22) that ϑ and τ doubly index the $\alpha^{\vartheta}(\mathrm{OP_{t-1}})$ and $\alpha^{\vartheta}(\mathrm{OP}^{\tau})$. We assume OP^{τ} is the function of τ, also, the functions of ϑ and OP^{τ} are $\alpha^{\vartheta}(\mathrm{OP_{t-1}})$ and $\alpha^{\vartheta}(\mathrm{OP}^{\tau})$. Similarly, the functions of θ and τ are $\alpha^{\vartheta}(\mathrm{OP_{t-1}})$ and $\alpha^{\acute{\vartheta}}$ (OP^{τ}). In addition, $\alpha^{\vartheta}(\mathrm{OP_{t-1}})$ and $\alpha^{\acute{\vartheta}}$ (OP^{τ}) can be redefined as $\alpha_0(\vartheta,\ \tau)$ and $\alpha_1(\vartheta,\ \tau)$. Thus, Equation (22) can be redefined as:

$$\alpha^{\vartheta}(\mathrm{OP_{t-1}}) = \alpha^{\vartheta} = \alpha^{\vartheta}(\vartheta,\ \tau) + \alpha_1(\vartheta,\ \tau)(\mathrm{OP_{t-1}} - \mathrm{OP}^{\tau}) \tag{23}$$

We get Equation (24) by replacing (21) into (23)

$$\underbrace{GBI_t = \alpha_0(\theta,\ \tau) + \alpha_1(\vartheta,\ \tau)(\mathrm{OP}_{t-1} - \mathrm{OP}^{\tau}) + \varepsilon_t^{\vartheta}}_{*} \tag{24}$$

The section (*) of Equation (24) is the ϑ th conditional quantile of OP. However, due to ϑ and τ doubly index α_0 and α_1, the expression reveals the causality between the ϑ th quantile of OP and the τth quantile of GBI. This is how it differs from the standard conditional quantile function. At the same time, no linear relationship is assumed between the quantiles of the variables.

Estimating Equation (24), requires replacing OP_{t-1} and OP^{τ} with their estimated counterparts OP_{t-1} and OP^{τ}. We can obtain the local linear regression estimates of σ_0 and σ_1 through figuring out the problem:

$$\min_{\sigma_0,\ \sigma_1} \sum_{i=1}^{n} \rho_{\theta}\left[GBI_t - \sigma_0 - \sigma_1(\widetilde{\mathrm{OP}_{t\bar{1}}} - \widetilde{\mathrm{OP}^{\tau}})\right] \times K\left(\frac{F_n(\widetilde{\mathrm{OP}\tau})\bar{\tau}}{h}\right) \tag{25}$$

$\rho\vartheta(\varepsilon)$ as a quantile loss function can be defined as $\rho\vartheta(\varepsilon) = \varepsilon(\vartheta - \mathrm{I}(\varepsilon < 0))$. I denotes an indicator function. h indicates the bandwidth parameter of the kernel and

$K(\cdot)$ indicates the Gaussian kernel function. In nonparametric estimation methods, the choice of bandwidth is significant because it can determine the size of the neighbourhood near the target point and explore the smoothness of the resulting estimation. When choosing a bandwidth, too large and too small will lead to biased and more considerable variance results, respectively, so we need to choose an appropriate bandwidth (Shahbaz et al., 2018). Constant bandwidth is not desirable because of biases (Li & Yuan, 2021). Thus, this paper uses $h = 0.05$ based on Sim and Zhou (2015).

5. Data

This paper chooses the monthly data covering the period from 2011:M1 to 2021:M11 to test the causality between the green bond market and OP and then investigate whether OP can stimulate the prospects of green bonds. In the development of the social economy, crude oil contributes to most energy consumption and has an unshakable position in the global energy system. However, the burning of crude oil brings severe environmental problems, such as the emission of GHGs that contribute to global warming. Over the past decade, the government has actively promoted the development of renewable energy projects, and investment in green projects has also flourished (Kyritsis & Serletis, 2019; Xia et al., 2019). Green bonds have been created as a financing vehicle, with a "green bond boom" in the bond market due to its response to the climate and sustainability investment initiatives of the Paris Agreement (Schryver & Mariz, 2020; Zhou & Cui, 2019). The attraction of green bonds as a viable financial instrument for their ability to hedge against volatility in commodity market prices is also confirmed by Naeem et al. (2021). To represent the green bond behaviour, we collect the S&P green bond select index denominated in U.S. dollars from S&P Global[1] (Park et al., 2020). The S&P Green Bond Select Index consists of a collection of global bonds that have been labelled "green" by the CBI and meet eligibility criteria (Ehlers & Packer, 2017). At the same time, to observe the oil market's volatility, we select OP of the U.S. dollar-denominated West Texas Intermediate (WTI) from wind (Wang et al., 2011; Chiroma et al., 2015). The regression series is decomposed into short-term, medium-term and long-term. The short-term shows the effect of OP on GBI from 1 to 16 days. The OP effect on GBI in the medium-term range of 32 to 64 days. Likewise, the long-term range evaluates changes from 128 to 256 days. Previous research has shown a strong interrelation between the oil market and the green bond market, implying that there may be a causal relationship between OP and GBI.

Figure 1 indicates the trends in GBI and OP. Since 2011, the global economic situation has improved, and the OP has risen. High OP has inspired the issuance of green bonds. The issuers of global green bonds are mainly multilateral development banks such as European Investment Bank (EIB), The World Bank and International Finance Corporation (IFC). The OP has fallen sharply since 2014 due to political events such as the Russia-Ukraine conflict. The price declined further leads to the depreciation of crude oil-producing countries, it causes crude oil production costs to decrease and production to increase, finally resulting in a negative circulation. After 2013, the global green bond market began to develop gradually, with annual issuance

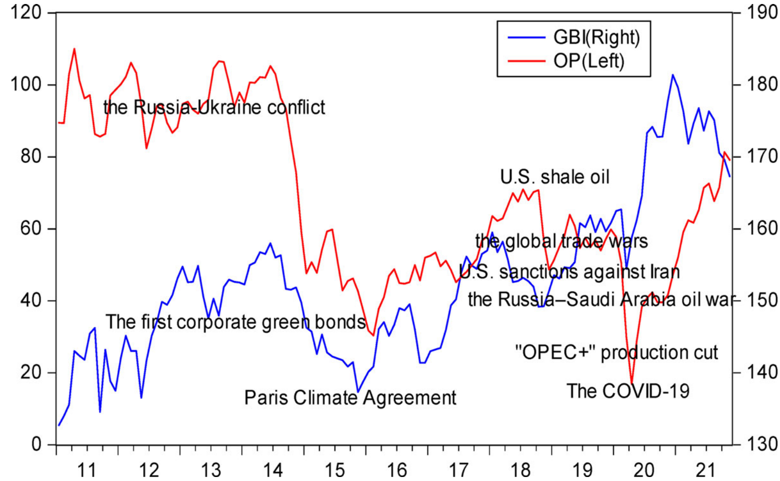

Figure 1. The trends of GBI and OP.
Source: Author Estimation.

rising rapidly from USD 11 billion in 2013 to USD 37.5 billion in 2014 and USD 42.5 billion in 2015. Between 2013 and 2014, more private sectors, including private companies and commercial banks, participate in green bond issuance. However, investors' demand for green bonds decreases due to the shock of the low OP, and the GBI decreases during 2014. In 2015, US shale oil production continued to increase, Saudi Arabia continued to produce oil on a large scale, and Iran reached a nuclear negotiation agreement. These events trigger further oversupply of crude oil and OP falls. At the same time, it is increasingly vital to divest fossil energy projects and provide financial allocations for the transition to a climate-resilient economy. The 2015 Paris Climate Agreement spurs investor interest in the financial opportunities associated with green projects (Reboredo, 2018). The green bond market attracts the attention of different issuers and investors, including small and medium-sized institutions, insurance companies, pension funds, mutual funds and individual investors. The green bond market develops, and the GBI rises. In 2018, the development of the global economy was severely restricted by the worldwide trade disputes represented by the Sino-U.S. trade war, and both GBI and OP have a downward trend. The GBI declines slightly in early 2020 as OP falls due to the Russia–Saudi Arabia oil war and the effect of the COVID-19 outbreak, which threat the green bond market. Therefore, there is a complex causality between the two variables.

Table 1 presents descriptive statistics. We can observe that GBI and OP's averages are concentrated at the 152.806 and 68.367 levels. The positive and negative skewness represent right-skewed distribution and left-skewed distribution, respectively. We can find that GBI and OP are right-skewed distribution. A kurtosis greater than three manifests that the series satisfies a leptokurtic distribution; otherwise, it has a platykurtic distribution, so according to the results, we find that GBI satisfies a leptokurtic distribution while OP satisfies a platykurtic distribution. Moreover, the Jarque-Bera test can prove whether the series is non-normally distributed. The results show that GBI is significantly non-normally distributed at the 1% level, while OP is satisfied at the 5% level.

Table 1. Descriptive statistics for GBI and OP.

	GBI	OP
Observations	131	131
Mean	152.806	68.367
Median	151.940	62.150
Maximum	181.390	110.040
Minimum	132.700	16.810
Standard Deviation	10.784	23.110
Skewness	0.715	0.192
Kurtosis	3.091	1.774
Jarque-Bera	11.219***	9.014**

Note: *** and ** denote significance at the 1% and 5% levels, respectively.
Source: Author Estimation.

6. Empirical results

We present the QQ results of the effect of OP on GBI under the original, short-, medium-, and long-term series in Figure 2, respectively. The value on the z-axis can detect the ϑth quantile of OP applies to the ϑth quantile of GBI. The results of the original data show that the impact of OP on GBI is primarily positive. Notably, the coefficients become positive and conspicuous when OP and GBI range in the quantiles of [0.75, 0.85] and [0.1, 0.2]. In the short term, the impact of OP on GBI is also mostly positive. The highest impact is found in the medium quantile, and it indicates that OP at the medium quantile has a positive influence on GBI. The positive effects can prove that OP can affect the prospects of green bonds. OP and GBI move in the same direction, and green bonds can be viewed as an efficient tool to hedge the risk of OP shocks. Since 2014, the global economic slowdown has reduced demand for oil and coupled with an oversupply of crude oil, oil prices have fallen sharply. A sharp drop in OP can be found by early 2015, accompanied by some frequent price swings. The fall of OP has impacted flourishing green projects (Banga, 2019). The low OP can improve production profit and reduce green investment from a cost angle analysis. In addition, green projects have high construction costs compared to the cost of oil, which is a significant barrier to finding renewable energy (Ferrer et al., 2018; Su et al., 2022b). Therefore, any considerable OP drop will restrict green projects' attraction and economic viability and lead to an abrupt halt in their development, adversely affecting GBI.

The impact of OP on GBI is primarily negative in the medium term, and we can find that in the upper quantile, OP has a significant negative effect on GBI. In addition, we can observe that OP influences the GBI negatively in the long term, and the most decisive influence is detected in the lower quantile. The negative effects cannot be evidence that OP and GBI move in the same direction, and the green bond can be considered an effective tool to avoid the risk of OP shocks. In 2018, U.S. shale oil production hit new heights, which made the U.S. become the world's largest oil producer. The Organization of Petroleum Exporting Countries (OPEC) is no longer the only significant source of oil purchases for energy-consuming countries. OPEC's implementation of a deeper agreement to reduce production has failed to prevent the growth of U.S. shale oil production (Khan et al., 2021). This has led to oversupply in the oil market and lower OP. Because of the excess, the fall in OP cannot attract investors to invest. Green bonds have attracted investors who want to contribute to the energy transition and environmental protection (Dorfleitner & Grebler, 2022;

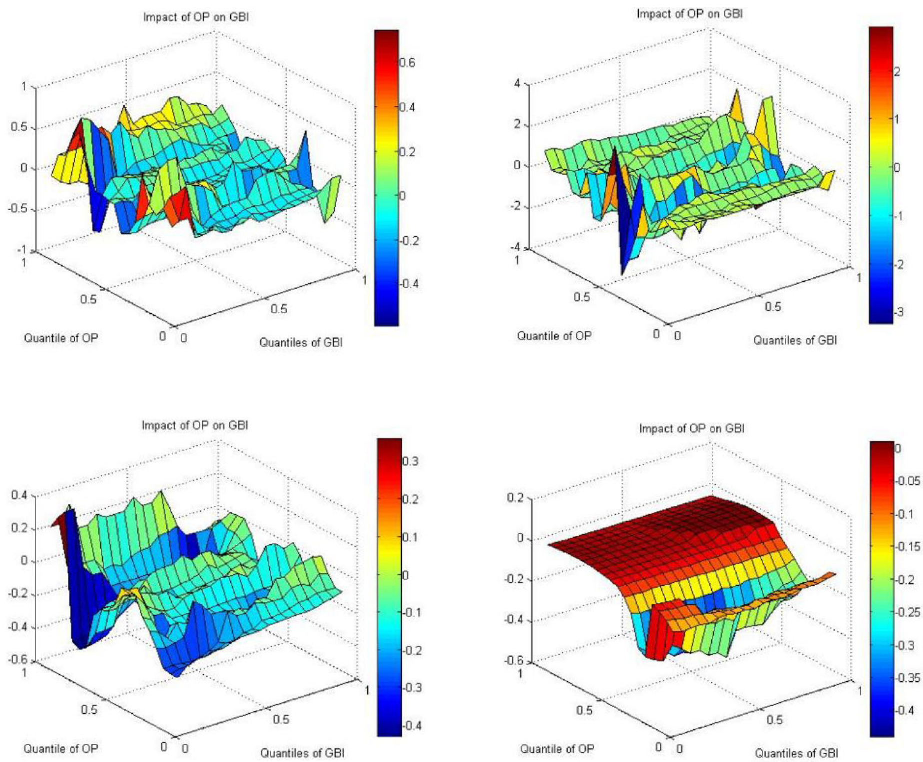

Figure 2. Impact of OP on GBI.
Source: Author Estimation.

Ferrat et al., 2021; Lobato et al., 2021). They invest in green bonds not mainly to obtain high yields but to be part of the green development process (Ferrer et al., 2021; Ielasi, 2018). In addition, oil is primarily used in transportation and production projects, while renewable energy is dedicated mainly to power generation. (Dutta et al., 2020b). Therefore, by not being direct substitutes, the impact on green investment demand may be positive when OP falls. As technology advances, technologies to produce renewable energy constantly improve, reducing production costs (Ferrer et al., 2018). This also attracts more funds into a green investment, further promoting the rise of the GBI. Due to the more convenient financing methods for green energy projects and the continuous reduction of operating costs, green energy companies have higher profits. This also keeps green bond values from moving in the same direction as oil prices (Combes et al., 2017). In 2019, the production cut agreement signed by OPEC and Russia took effect in January. The exemption of U.S. sanctions against Iran expires in May, which has made significant progress in eliminating oversupply combined with OPEC production cut. In addition, the increase in U.S. shale oil production is also lower than expected, and the combined effects of these aspects led to the rise of OP in 2019. Statistics from the CBI show that the issuance of global green bonds reached USD 257.7 billion in 2019. However, unilateralism, protectionism and populism become more unbridled in 2019, resulting in many negative new situations and problems (Paul, 2021). Rising trade disputes and geopolitical tensions have increased volatility and risks in the world economy (Cunado et al., 2020). The

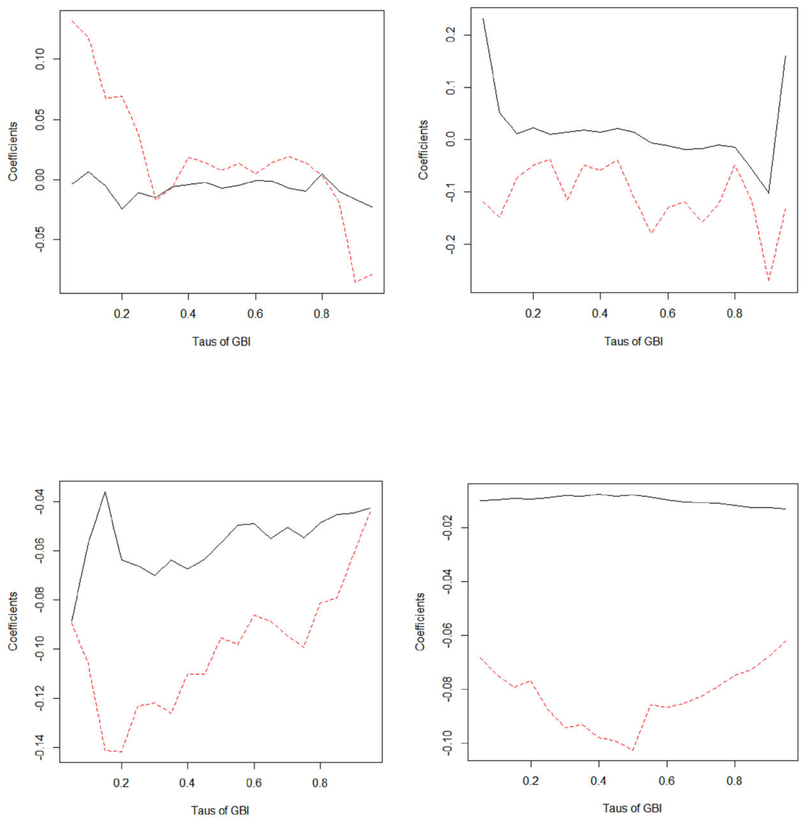

Figure 3. QQ estimates and Quantile Regression.
Note: The red line represents QQ estimates and black line represents Quantile Regression.
Source: Author Estimation.

world's major economies are generally sluggish, making investors reduce their investment in green bonds. Therefore, we concur that OP can negatively affect GBI.

QQ can decompose estimates for quantile regression and allow specific estimates for different quantiles of explanatory variables. In the paper, the θth quantile of OP on GBI is the basic quantile regression. θ and τ index the parameters of OP and GBI. In different quantiles, QQ is heterogeneous and can be used to recover the estimates of the standard quantile regression. Therefore, ϑ can index the quantile regression's parameters, it can be estimated by averaging the QQ parameters along τ. Slope coefficients show the influence of OP on GBI, $\gamma_1\vartheta$ can represent:

$$\gamma_1\vartheta \equiv \overline{\hat{\beta}_1}(\vartheta)\frac{1}{s} = \frac{1}{s}\sum_{\tau}\hat{\beta}_1(\vartheta,\tau) \quad (26)$$

s is quantile numbers $\tau = [0.10, 0.15, \ldots .0.90]$.

Figure 3 shows the validity outcome by quantile regression and QQ estimates. With these results we can learn more about the impact of OP on GBI. We found that in the short term, OP had a positive effect on GBI, while in the medium and long term, the effect was negative.

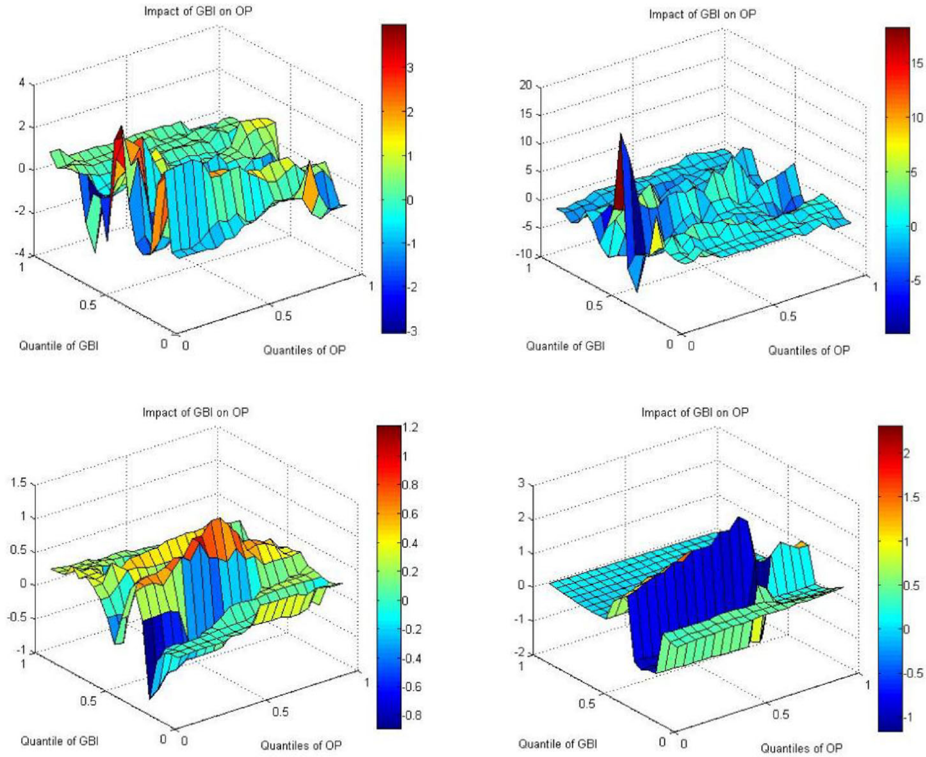

Figure 4. Impact of GBI on OP.
Source: Author Estimation.

We present the QQ results of the impact of GBI on OP under the original, short-, medium-, and long-term series in Figure 4, respectively. The outcomes of the original data show that the impact of GBI on OP is primarily positive. Remarkably, the coefficients become positive and conspicuous when GBI and OP range in the quantiles of [0.4, 0.5] and [0, 0.1]. In the short term, the impact of GBI on OP is also mostly positive. The highest impact is found in the medium quantile, and it indicates that GBI at the medium quantile results in an increase in OP. It can prove that green bonds cannot be viewed as efficient measures to alleviate the oil crisis. According to a report released by the CBI, the global green bond market's issuance was USD 11 billion in 2013. This shows that the green bond market has a good development momentum, and GBI has increased. However, the oil demand continues to grow, driven by the recovery of the global economy (Hammoudeh et al., 2010). Supplies have been reduced by political instability in the Middle East, such as the war in Syria and the civil war in Libya (Su et al., 2021a). Furthermore, due to the implementation of policies such as quantitative easing, as the OP's denomination currency, the U.S. dollar has been devalued (McLeod & Haughton, 2018). The above reasons lead OP to remain high during this period. Despite the rapid growth of green bonds, it is only a small scale in the overall bond market due to its small base (Sartzetakis, 2021). The development of the green bond market cannot reduce consumers' dependence on oil and reduce OP.

The impact of GBI on OP is mostly positive in the medium term, and we can find that in the medium quantile, GBI has a significant positive effect on OP. In addition, it shows that the GBI influences the OP positively in the long run, and the strongest influence is detected in the medium quantile. In the second half of 2019, the green bond market has also been adversely affected by the anti-globalisation and the downturn of the world economy, and the GBI has declined. At the same time, the rise of the USD and market doubt about the ability of OPEC to implement the production cut plan reduce OP. In addition, the dramatic increase in U.S. crude oil inventories also leads to a decline in OP. In early 2020, Nino Virus (COVID-19) broke out, severely impacting the entire financial market. Due to fluidity risks, assets face extreme downlink risks (Gulseven et al., 2020; Rizvi et al., 2020a, 2020b; Tao et al., 2021). During this time, green bonds are affected by the epidemic. This is not conducive to the prosperity of the green bond market, and the GBI falls. Similarly, COVID-19 has caused a massive hit on the oil market; many industries have stopped production, which causes a reduction in oil demand, thereby OP to fall (Hanieh, 2021; Yarovaya et al., 2020a; 2020b; 2021). In addition, the collapse of OPEC and the failure to sign the Russian production cut agreement also exacerbate the OP's decline. After mid-2020, green finance has shown vigorous vitality in promoting economic recovery and green transformation, and green bonds have made innovative development in the process of fighting the epidemic. The global green bond issuance will reach a record USD 269.5 billion in 2020. The green bond market

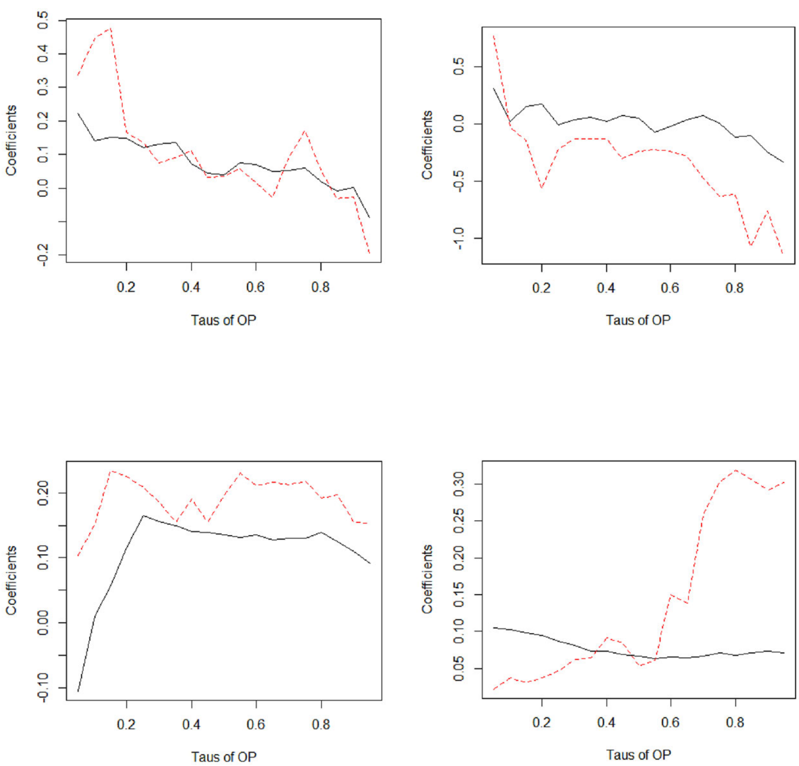

Figure 5. QQ estimates and Quantile Regression.
Source: Author Estimation.

flourishes and GBI rises. However, the economic recovery increases the demand for oil and the OP (Wang & Zhang, 2021). In addition, the "OPEC+" alliance implements production cuts to reverse the oversupply of oil, which also increases OP (Quint & Venditti, 2020).

Figure 5 describes the QQ regression results that denote the effect of different measurements. It proves that the effect of GBI on OP is positive in all quantiles. This finding denotes that the influence is more causative in the short run. The positive influences of GBI on OP can indicate that green bonds cannot be viewed as efficient measures to alleviate the oil crisis.

To sum up, in the short run, there is a positive influence from OP to GBI, it proves that green bonds can be considered assets to avoid the OP shocks. At the same time, we can also recognise that oil and green bonds belong to the same camp because the value of green bonds will increase as the OP rises. Nevertheless, in the medium and long term, the effect of GBI on OP is consistently positive across all the quantile due to the oversupply of the oil market and the high-profit rate of the green energy industry. These outcomes are identical to the supply and demand-based correlation model of green bonds and oil price, suggesting that OP can affect GBI, but the direction cannot be identified. In turn, the impact of GBI on OP is consistently positive across all the quantile. Considering the instability of the Middle East, the COVID-19 and the small scale of green bonds, the OP will increase with the rise in GBI. Green bonds cannot be considered efficient measures to alleviate the oil crisis.

7. Conclusion and policy implications

In this paper, we discuss whether OP can affect the prospects of green bonds by utilising the QQ method. According to the empirical results, we find that OP's impacts to GBI are positive in the short run. The positive impact can prove that OP can affect the prospects of green bonds, and the increase of the OP can cause GBI to rise. Nevertheless, in the medium and long term, there is a negative impact due to the oversupply of the oil market and the increase in green energy industry profits. These results are identical to the supply and demand-based correlation model of green bonds and oil price, suggesting that OP can affect GBI, but the direction cannot be identified. From the other direction, the finding reveals that the GBI effect on OP is consistently positive across all the quantile, and it indicates that green bonds cannot be considered as efficient measures to alleviate the oil crisis due to the instability of the Middle East, the COVID-19 and the small scale of green bonds.

These conclusions have some important implications. Green bonds are developing rapidly in the international financial market and occupying a growing share of the overall global debt market, attracting not only ESG-focused investors but also traditional fixed-income investments that have not previously "green" their portfolios. The issuers, investors and investment projects are becoming more diversified. The market prospect is promising, but it also faces challenges. On the one side, the participants of the green bond market can make decisions based on OP. Since green bond issuers such as oil-importing countries need to diversify their energy sources, they are likely to respond to this change by issuing large volumes of this bond when OP increases. Green bond assets can be seen as a hedging tool for fluctuating OP. Investors can incorporate green bonds into their portfolio and diversify investments to adapt to the market environment. In addition, the green bond can be used as the basic asset for the green financial market, and other financial products can be activated, thereby attracting more types of investors. On the other side, the green bond market is still small, and investors' understanding of green investments is still limited. But with the growing importance of the oil issue, the potential for further growth in the green bond market is huge. Some measures need to be taken to promote the growth of the green bond market. It is critical to improving the market mechanism to enhance the ease of issuance and investment of green bonds. Policies such as interest discounts should apply to green bonds. Policymakers can help increase the supply of green bonds and formulate supportive policies that promote the development of the renewable energy sector. Providers of public capital can de-risk renewable assets and provide seed capital, demonstration issuances and capacity building to support green bonds. Institutional investors can help by aligning their internal capabilities and investment objectives with long-term sustainability mandates.

There are also some limitations of our study, which also provide directions for future research. Firstly, this paper only examines the correlation between oil and green bonds to research whether the changes of OP can affect the prospect of green bonds. However, expect OP, there may exist other factors that affect the development of the green bond market, such as gold prices. In future research, we can further explore green bonds by studying the relationship between factors such as gold prices and green bonds. Secondly, this paper applies the QQ method to study the causality between the OP and GBI, and there are many other methods to study the causal relationship between them. In order to fully understand the relationship between them, we can use other methods in future research. Finally, this paper studies the impact of OP changes on green bonds from a global perspective. In future research, we can conduct research on whether OP in certain countries or regions can affect the development of green bonds in that region.

Note

1. The website of S&P Global is https://www.spglobal.com.

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ORCID

Chi Wei Su http://orcid.org/0000-0001-9722-8105

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