Does Bitcoin affect decomposed oil shocks differently? Evidence from a quantile-based framework

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Abstract

This paper studies the impact of Bitcoin on decomposed oil price shocks within a quantile-based framework, through which the underlying investment sheltering role of Bitcoin for various oil price fluctuations is explored. The aggregate oil price shock is decomposed into three perspectives of the demand, the supply, and the changing attitudes towards risk. A comparison of the sheltering role between Bitcoin and gold is further evaluated. By using a non-parametric causality test, we find that there exists an asymmetric and unidirectional causal relationship from Bitcoin/gold to oil shocks. Such the unidirectional causality appears only to the demand and supply shocks of oil instead of the risk-specific shocks, and is more evident at median quantiles. By jointly considering the data distribution of both dependent and independent variables realized by a quantiles-on-quantiles method, both Bitcoin and gold generally depict the hedge and safe haven abilities for oil shocks, and such the ability is shown to be different not only between Bitcoin and gold but also for various sources of oil shocks. The sheltering role of gold is found to be greater than that of Bitcoin for the supply shock, while the results reverse for the demand shock. Moreover, shocks from the identified shocks from the COVID-19 pandemic and the Russia-Ukraine conflict are found to not change the cross-market relationship. A series of robustness checks confirm our findings that possess important implications for various stakeholders.

Keywords: Bitcoin; Decomposed oil shocks; Investment shelter; Causality-in-quantiles; Quantiles-on-Quantiles

1. Introduction

Despite the growing popularity of eco-friendly energy sources in the process of low carbon transition, crude oil has long been a crucial energy input that drives output production and economic operations worldwide(Cherp et al., 2018; Ghasemian et al., 2020). According to the International Energy Agency (IEA), the proportion of crude oil consumption still constitutes more than one third of the overall global energy consumption in 2021.[1] Recently, oil prices have witnessed an increasingly high fluctuation and plunged to even negative values for the first time in history on April 20, 2020. The marked fluctuations in the oil market have therefore long raised widespread attention worldwide. Studies by far attribute significant increases in oil price volatility to various reasons notably including market demand and supply shocks (Fattouh and Economou, 2020; Chatziantoniou et al., 2021) and reliance on liquidity factors (Le et al., 2021). This has accordingly called for sensible management of oil asset related investment portfolios with dual targets of maximizing profits and sheltering against the downside risk.

Since the oil market dynamics can be driven by various sources such as shifting of the demand and supply of oil (Herrera et al., 2019; Fattouh and Economou, 2020; Chatziantoniou et al., 2021), the seemingly same oil price rise/decline might be underpinned by different forces that would lead to heterogeneous reactions and associated risk accumulation in the economy (Lee et al., 2017; Malik and Umar, 2019). While simply relying on the aggregate oil price series would mask the individual oil-related risk dynamics (Uddin et al., 2018), existing effort on hedging against the latter remains rather scant. Lately, the role of Bitcoin as a potential investment shelter against financial assets and commodities including oil has been raised an emerging attention (Luther and Salter, 2017; Ren et al., 2022; Wen et al., 2022).

[1] Data are sourced from the World Energy Outlook 2021 by IEA (https://www.iea.org/reports/world-energy-outlook-2021).

Relative to traditional safe-haven assets such as gold (Baur and Lucey, 2010; Conlon et al., 2018), Bitcoin has sheltering effect against the oil market due to its weak correlation with political and economic fluctuations of Sovereign nations(Conlon and McGee, 2020a; Shahzad et al., 2019; Selmi et al., 2018). However, existing literature points out that Bitcoin's high volatility, low liquidity, and high transaction costs undermine its safe heaven ability (Smales, 2019). During market depression, Bitcoin would have a weak store of value due to its strong speculative nature (Baur et al., 2018). By far, there is no consensus on the sheltering role of Bitcoin for oil-related assets, and in-depth research on the underlying differences in this role across decomposed oil shocks remains limited. This therefore necessitates a clear comprehension of effective investment shelters for adverse fluctuations in oil prices induced by shocks from different sources. Nevertheless, by far, several important questions remain to be answered. Whether and how different would Bitcoin relate to the aggregate oil price and its decomposed components? Whether and how is the investment sheltering role of Bitcoin different to that of the traditional shelter (gold)? What is the underlying reason to explain the obtained findings?

To this end, this paper decomposes the oil price series into shocks from different sources and then studies the possibly investment sheltering role of Bitcoin for different types of oil price shocks in a quantile-based framework. Within the framework, the causality between Bitcoin and oil shocks is tested by using a non-parametric causality-in-quantiles test(Jeong et al., 2012). The potentially asymmetric market relationship between Bitcoin and oil shocks over the full data distribution is then evaluated by employing the recently-employed quantiles-on-quantiles (QQ) approach of Sim and Zhou (2015). To compare the sheltering role between Bitcoin and gold, the relationship between gold and various oil shocks is further investigated across quantiles of the data distribution. In addition, potential structural breaks in our research sample are detected by methods of Bai and Perron (1998, 2003), and whether the sheltering role of Bitcoin/gold changes when facing shocks in exogenous events such as the COVID-19 pandemic and the Russia-Ukraine (RU) conflict is further examined.

The contribution of our paper is three-fold. First, we exploit micro-level information by evaluating the investment sheltering effect of Bitcoin/gold on various decomposed oil price shocks, rather than simply using an aggregate oil price series as in extant literature (See, e.g., Selmi et al., 2018; Ren et al., 2022; Naeem et al., 2022). The above employed strategy is due to the potentially distinct response of the economy when facing oil price changes driven by different types of shocks. Relying on the aggregate data would otherwise mask or even bias the result. In specific, oil demand shocks due to global economic expansion eventually lead to higher oil prices, while at the same time, oil supply shocks related to oil production disruptions may lead to significant oil price increases (Uddin et al., 2018), and risk factors from economic policy uncertainty may also influence oil market to some extent. Therefore, considering the response of aggregate oil price changes to other financial assets may be misleading. This argument also helps explain the seemingly-elusive findings regarding the weak relation between the oil market and the economy.

Second, we are among the first to explore the relationship between Bitcoin/gold and oil shocks over different market conditions using both nonparametric causality tests and quantile-on-quantile (QQ) method. Once identifying that the uni-directional causality from Bitcoin/gold to oil shocks, as a coherent and further discussion, we quantify the impact magnitude of Bitcoin/gold in a joint-distribution setting that includes both dependent and independent variables by using a QQ method. Our research extends the literature by exploring the underlying-distinct sheltering role of Bitcoin/gold against various oil price shocks at different market conditions by studying the causality and the impact of Bitcoin on various oil shocks under a quantile-based framework.

Third, we further consider the impact of exogenous shocks on the relationship between Bitcoin/gold and oil by identifying structural breaks. The breaks identified from oil price dynamics corroborate with the recently important international events, i.e., the COVID-19 pandemic and the RU conflict. Whether the cross-market relationship is altered when facing exogenous shocks is further checked by employing the causality test and QQ estimation in each sub-period divided by the above two events. We further eliminate the impact of other potential exogenous shocks in each sub-period to only focus on the dynamics of the market relationship caused by the pandemic onset and the RU conflict. Our study enriches the literature related to whether COVID-19 affects the sheltering role of Bitcoin/gold on the oil market(Al-Nassar et al., 2022; Wen et al., 2022; Ji et al., 2020) and is among the first to explore the impact of the Russian-Ukrainian conflict on the relationship between Bitcoin/gold and oil/shocks.

Our main findings are summarized below. As for the causality-in-quantiles test, there is an unidirectional causal relation from both Bitcoin and gold to series of the crude oil price series, as well as its decomposed supply and demand shocks of oil, but not the other way round. While the causality to oil prices and the decomposed supply shocks is significant in all but a few extreme market conditions, that to the decomposed demand shocks tends to mainly exist at normal market conditions. Moreover, Bitcoin/gold returns appear to not connect with the corresponding market risk shocks over the data distribution.

Regarding the QQ estimates, Bitcoin and gold generally contribute to diversification benefits and risk mitigation for oil price fluctuations. The sheltering role is shown to be different not only between Bitcoin and gold but also across different sources of the oil price dynamics. In specific, for the aggregate level of oil price series, price returns of Bitcoin behave a flat impact pattern on that of crude oil that the impact magnitude is relatively stable and remains as weakly positive at most of quantiles over the data distribution. In contrast, the impact of gold returns demonstrates a quasi-monotonic increasing pattern with increases in oil quantiles, and the impact turns to be even negative in oil market depression.

For the decomposed oil supply shock, Bitcoin and gold exert an opposite impact pattern that the impact of Bitcoin return depicts a decline with increases in quantiles of oil shocks but that of gold reaches its low level when oil quantiles are extremely low. The magnitude of the impact range of Bitcoin returns over the data distribution is generally larger than that of gold. For the decomposed oil demand shocks, Bitcoin offers a sheltering effect that increases as the oil market condition improves, and its impact magnitude is overall equal or less than zero. In contrast, the effect size of gold could be relatively larger that it is highly positive at extremely high quantiles of oil demand shocks, and it declines gradually and even becomes negative at low oil quantiles. Thus, the sheltering role of gold for the supply shocks is found to be more evident than that of Bitcoin, while the results reverse for the demand shock of crude oil. Additional analysis suggests that shocks from international events such as the COVID-19 pandemic and the RU conflict generally do not change the impact patterns of Bitcoin/gold on the oil market.

Noteworthy, the response of the supply and demand shocks in oil prices when facing Bitcoin/gold price changes is distinct. Such the individual and different response would otherwise be masked unless we decompose the oil price shocks from an aggregate level. Our findings survive a number of robustness checks such as alternative estimation strategies and proxy for oil prices. The findings possess important implications for effective management of uncertainties in oil price fluctuations from different sources, as well as shedding light on the investment sheltering role of both Bitcoin and gold.

The rest of the paper is organized as follows. Section 2 presents a succinct review of key literature. Section 3 describes our employed econometric methods and datasets. Section 4 reports estimation results and discusses corresponding theoretical explanations. Section 5 concludes.

2. Literature review

Our research is related to at least the following two strands of the literature, i.e., the investment sheltering of gold and Bitcoin for financial assets and commodities, especially the oil-related assets. Gold, as one of the earliest forms of money, has been commonly considered as an effective hedge and safe haven for financial and other commodity assets against market turbulence (especially during market downturns). Extensive literature has shown a weak/negative relationship between gold and financial assets, revealing the investment sheltering role of gold as a hedging and/or safe haven (See, e.g., Chua et al., 1990; Upper, 2000; Ciner, 2001; Hillier et al., 2006; Kaul and Sapp, 2006; Baur and Lucey, 2010; Ciner et al., 2013; Reboredo, 2013; Dutta et al., 2020).

Despite the widespread confirmation by the literature, the role of gold is also found be volatile and can change dramatically with different asset types and market conditions. Baur and Lucey (2010) find that gold can serve as a hedge against stock markets, and even act as an effective safe haven during the crises, but such the role is not applicable for bonds. Ciner et al. (2013) examine whether and to what extent the five major assets (i.e., stocks, bonds, oil, gold, and the U.S. dollar) can provide a hedge or shelter function for each other. The results suggest that gold can play a safe haven role for most assets except for oil. Reboredo (2013) suggests that gold cannot simultaneously serve as a hedge against oil price changes, but it can be a safe haven against extreme oil price volatility. Selmi et al. (2018) employ a quantile-on-quantile regression method to obtain evidence that gold can act as a safe haven, hedge, and diversifier against oil, but these effects can be sensitive to market conditions of gold and oil prices. Ji et al. (2020) assess whether tail changes in equity indices can be offset by introducing safe-haven assets and find that only gold and commodity futures remain strong as safe-haven assets after the outbreak of COVID-19, Chemkha et al. (2021) reach similar conclusions when they reassessed the effectiveness of gold as a hedging asset in reducing risk in international portfolios and demonstrated that gold was an effective instrument against tail risk during the COVID-19 pandemic. Akhtaruzzaman et al. (2021) study the potentially hedging role of gold during the COVID-19 pandemic and show that gold could offer different degrees of hedging roles at different phases of the pandemic.

Although gold is widely considered as an investment shelter, its sheltering property has been recently questioned with the intensification of zero interest rates and the global financialization (Shahzad et al., 2019). Alternatively, Bitcoin, being termed as the "digital gold", has demonstrated its resilient and independence with the financial market (Wang et al., 2022) so that its role as a hedge and safe haven has received widespread attention by far (Conlon and McGee, 2020a; Shahzad et al., 2019; Selmi et al., 2018; Dyhrberg, 2016; Baur et al., 2015; Al-Khazali et al., 2018; Bouoiyour and Selmi, 2017, 2015). Similar to that of gold, existing literature on the sheltering role of Bitcoin produces inconsistent conclusions. Some empirical evidence points out that the sheltering role of Bitcoin tends to be weak. For example, Baur et al. (2015) show that Bitcoin is correlate insignificantly with traditional commodities such as stocks, bonds, and commodities under different market conditions. Bouri et al. (2017b) study the impact of Bitcoin on commodity markets. They find that the hedging and safe haven properties of Bitcoin disappear after the Bitcoin price crash in December 2013 and show only weak diversification benefits against the non-energy commodity indices. Moreover, Bouri et al. (2017c) indicate that Bitcoin can only provide diversification to world stock markets and the US dollar, while producing a poor hedge. Bitcoin's sheltering role varies across economies and could only serve as a safe haven for Asian stock markets during extreme downturns. Kang et al. (2019) study the linkage between Bitcoin and gold futures using dynamic conditional correlations (DCCs) and wavelet coherence. They find a high degree of co-movement between Bitcoin and gold during the crisis, thus limiting the safe-haven feature of Bitcoin. The study by Disli et al. (2021) also shows that Bitcoin has no safe-haven property. Instead, it becomes a diversification tool for investors over a longer horizon after the COVID-19 outbreak.

At the same time, there is a body of literature speaking in favor of the sheltering and hedging role of Bitcoin. Dyhrberg (2016) finds the hedging properties of Bitcoin, which can be incorporated into portfolios to reduce the adverse effects of market volatility. Bouri et al. (2018) analyze the sensitivity of Bitcoin to global financial stress and demonstrate that Bitcoin can be a safe haven under conditions of financial turmoil. Bouri et al. (2017a) use an option implied volatility index to represent global economic policy uncertainty and find that Bitcoin is an effective hedge against uncertainty in major developed and developing markets. Shahzad et al. (2019) propose new definitions of weak and strong safe havens based on the tail distribution of assets, and found that each of Bitcoin, gold, and commodity indices can be considered weak safe-haven assets using the bivariate cross-quantilogram approach. Raheem (2021) documents that bitcoin provides a safe haven for investors, although this ability to withstand tail risk became uncertain after the COVID-19 outbreak. Similar empirical evidence is further obtained, speaking in favor of the sheltering role of Bitcoin against adverse financial fluctuations (See, e.g., Demir et al., 2018; Wang et al., 2019; Wu et al., 2019).

In terms of the market relation between Bitcoin/gold and crude oil, existing findings still remain to be mixed and even contradictory. One important reason might be that the oil price movements could be originated from different types of shocks. Kilian (2008) decomposes oil price changes into demand and supply shocks, and subsequent studies such as Hamilton (2009), Kilian and Lewis (2011) and Ahmadi et al. (2016) report under the framework of Kilian (2008), showing that different oil price shocks have asymmetric effects on the overall economy, real oil prices and inflation rates. Ready (2018) proposes an enhanced identification technique that decomposes oil price changes into different types of shocks, i.e., shocks from the demand, supply and risk perspectives of oil, and finds different impact patterns of various oil shocks on contemporaneous stock returns. One important inference is that merely considering the impact of Bitcoin/gold on the overall change in oil prices would produce biased conclusions. However, existing research on the role of Bitcoin for decomposed oil shocks is very limited. To the best of our knowledge, by far, there only exists one related study by (Das et al., 2020) which use a dummy variable GARCH and quantile regression model to explore the hedging effect of Bitcoin/gold on oil price shocks. Our research extends the existing litearture in the following manners. By using nonparametric quantile causality tests, we not only determine the causal relationship between Bitcoin/gold and shocks to oil price return and its decomposition, but also use a novel QQ estimation method to analyze whether Bitcoin/gold can be used as a safe haven, hedge, or diversification asset for oil. These techniques reveal the asymmetry and nonlinearity of the relationship between Bitcoin/gold and the oil market, and the use of causality tests makes the analysis more coherent and scientific. At the same time, we have further employed the approach of Bai and Perron (1998, 2003) to identify structural breaks and examine whether exogenous shocks alter these properties of Bitcoin/gold by comparing the estimates of sub-samples.

3. Methodology and data

3.1. The structural oil shock decomposition

In light of the existing literature, the sources of oil price changes have attracted substantial attention. In fact, economies may respond differently to oil price changes caused by varied types of shocks, and focusing only on aggregate level oil prices can obscure more microscopic phenomena(Uddin et al., 2018; Das et al., 2020). Thus, this paper employ the approach recently developed by Ready (2018) to decompose the changes in oil price into demand shocks, supply shocks, and risk shocks. We use three indexes, some measures of changes in (i) oil producing companies, (ii) oil price, and (iii) expected returns, to construct different types of oil shocks. In this case, the changes in the oil producer index can be measured by the return of MSCI All Country World Index, Energy Index, the return of Brent Crude Oil futures price can be used as a proxy for the oil price changes, and following to Ready (2018), the ARMA(1,1) process is used to identify the CBOE Volatility Index and the corresponding residuals are used to measure the expected returns changes. According to model in Ready (2018), volatility in the expected returns are used only as a source of risk shocks, while the demand shocks are defined as the portion of the current returns of the global index of oil producing companies that are orthogonal to the risk shocks, and the supply shock are defined as the remaining portion of the current oil price changes that are orthogonal to the demand and risk shocks. According to this construction, supply shocks(s_t), demand shocks(d_t) and risk shocks(r_t) can explain all the variation in oil prices. The three shocks are orthogonal and defined in the following manner:

$$Y_t = \begin{bmatrix} \Delta P_t \\ R_t^{Prod} \\ \xi_{VIX_t} \end{bmatrix}, S_t = \begin{bmatrix} s_t \\ d_t \\ r_t \end{bmatrix}, M \equiv \begin{bmatrix} 1 & 1 & 1 \\ 0 & a_{22} & a_{23} \\ 0 & 0 & a_{33} \end{bmatrix}, \tag{1}$$

where ΔP_t, R_t^{Prod} and ξ_{VIX_t} represent the return in oil price, the global oil producing companies and innovation in the VIX respectively. The matrix M maps the vector of shocks S_t into Y_t:

$$Y_t = MS_t, \tag{2}$$

and

$$M^{-1}\Sigma_Y \left(M^{-1}\right)^T = \begin{bmatrix} \sigma_s^2 & 0 & 0 \\ 0 & \sigma_d^2 & 0 \\ 0 & 0 & \sigma_r^2 \end{bmatrix}, \tag{3}$$

where Σ_Y is the covariance matrix of Y_t, the volatilities of the identified shocks are denoted as σ_s, σ_d and σ_r. Note that we restrict the sum of the identified shocks to the oil price change rather than one in the decomposition.

3.2. The quantile Granger causality test

After identifying the oil price shock, we employ the nonparametric causality-in-quantile test developed by Jeong et al. (2012) to explore the nonlinear causality between the Bitcoin/gold and oil/shocks. In contrast to traditional linear causality tests, this approach nonparametrically models the causal relationship between given two variables across quantiles of the variable potentially being as a cause, thus recovering possible nonlinearities in causality (Duan et al., 2021). This method fits with our focus on the relationship between assets in extreme cases, and has also been widely applied for examining the non-linear causal dynamics of financial series under different market conditions (Balcilar et al., 2017, 2016, 2018; Bahloul et al., 2018). We introduce the method in this section by taking x_t, y_t(the explanatory and explained vectors) as an example. Denote $Y_{t1} \equiv (y_{t1}, \ldots, y_{tp})$, $X_{t1} \equiv (x_{t1}, \ldots, x_{tp})$, $Zt = (X_t, Y_t)$, $F_{y_t|Z_{t-1}}(y_t, Z_{t-1})$ and $F_{y_t|Z_{t-1}}(y_t, Z_{t-1})$ represent the conditional distribution functions of y_t given Z_{t-1} and Y_{t1}, respectively. If we denote $Q_\theta(Z_{t1}) \equiv Q_\theta(y_t|Z_{t1})$ and $Q_\theta(Y_{t1}) \equiv Q_\theta(y_t|Y_{t1})$, we have $F_{y_t|Z_{t-1}}\{Q_\theta(Z_{t-1})|Z_{t-1}\} = \theta$ with probability 1. Then the hypotheses of causality test can be expressed as:

$$H_0 : P\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta\} = 1, \tag{4}$$

$$H_1 : P\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta\} < 1. \tag{5}$$

We calculate the distance measure as $J = \{\epsilon_t E(\epsilon_t|Z_{t-1} f_Z(Z_{t-1}))$ following Jeong et al.(2012) to obtain the metric for the implementation of the causality test, where ϵ is the regression error term and $f_Z(Z_{t-1})$ is the marginal density function of Z_{t-1}. ϵ arises from null hypothesis (4), which is true if and only if $E[I\{y_t \leq Q_\theta(Y_{t-1})|Z_{t-1}\}] = \theta$ or $I\{y_t \leq Q_\theta(Y_{t-1})\} = \theta + \epsilon_t$, where $I\{\cdot\}$ denotes the indicator function. The explicit expression of the distance function can be estimated as follows according to Jeong et al. (2012):

$$\hat{\mathrm{J}}_\mathrm{T} = \frac{1}{\mathrm{T}(\ \mathrm{T}-1)\mathrm{h}^{2\mathrm{p}}} \sum_{\mathrm{t=p+1}}^{\mathrm{T}} \sum_{\mathrm{s=p+1,\ s\neq p}}^{\mathrm{T}} \mathrm{K}\left(\frac{\mathrm{Z_{t-1}} - \mathrm{Z_{s-1}}}{\mathrm{h}}\right) \hat{\epsilon}_\mathrm{t}\hat{\epsilon}_\mathrm{s}, \tag{6}$$

where $K(\cdot)$ denotes the kernel function with bandwidth h, T is the sample size, and p is the lag-order used for defining vector Z_t and ϵ_t denotes the regression residual. ϵ_t, which could be defined as the follows:

$$\hat{\varepsilon}_t = \mathbf{1}\left\{y_t \leq \hat{Q}_\theta\left(Y_{t-1}\right)\right\} - \theta, \tag{7}$$

$\hat{Q}_\theta(Y_{t-1})$ is an estimate of the θ-th conditional quantile of y_t given Y_{t-1}. Below, we estimate $\hat{Q}_\theta(Y_{t-1})$ using the nonparametric kernel method as:

$$\hat{Q}_\theta\left(Y_{t-1}\right) = \hat{F}^{-1}_{y_t|Y_{t-1}}\left(\theta \mid Y_{t-1}\right), \tag{8}$$

where $\hat{F}_{y_t|Y_{t-1}}\left(y_t \mid Y_{t-1}\right)$ is the Nadaraya-Watson kernel estimator given by:

$$\hat{F}_{y_t|Y_{t-1}}\left(y_t \mid Y_{t-1}\right) = \frac{\sum_{s=p+1, s\neq t}^{T} L\left(\frac{Y_{t-1}-Y_{s-1}}{h}\right)\mathbf{1}\left(y_s \leq y_t\right)}{\sum_{s=p+1, s\neq t}^{T} L\left(\frac{Y_{t-1}-Y_{s-1}}{h}\right)}. \tag{9}$$

Utilizing the statistic $\hat{\mathrm{J}}_{\mathrm{T}}$, we test the Granger causality-in-quantile between Bitcoin/gold and oil/shocks. First, let the oil price change/shocks be y and test if the Bitcoin/gold returns can Granger-cause y. We then switch the explanatory and explained variables to explore whether oil price change/shocks can predict the Bitcoin/gold returns as the Granger cause. In addition to determining the Granger causality between Bitcoin/gold and oil/shocks, the test results also provide a more scientific basis for our subsequent quantile-to-quantile regressions.

3.3. The Quantile-on-Quantile approach

We further introduce the Quantile-on-Quantile(QQ) regression method proposed by Sim and Zhou (2015) in this section to provide a comprehensive and precise understanding of the relationship between variables under different market conditions. Compared with mean-based methods such as OLS and traditional quantile regression methods, the QQ method is more robust to outliers and non-normality in the actual data, especially its ability to reveal potential structural mutations in the data and relax the linear model assumed in traditional quantile regression to allow for the possibility of non-linear relationships between variables, thus comprehensively capturing the potential asymmetric effects of the explanatory variables under different market conditions on the distribution of the explained variable.

To further explicate the QQ method, we denote the returns on the Bitcoin/gold prices as X_t and changes in the crude oil futures and shocks as Y_t. First consider the nonparametric quantile regression equation for Y_t as a function of X_t as:

$$Y_t = \beta_0^\tau + \beta_1^\tau X_t + \alpha^\tau Y_{t-1} + \epsilon_t^\tau, \tag{10}$$

where Y_t represents crude oil futures price return and three types of identified shocks at time t in the follows, τ stands for the τ-quantile of Y_t and the residual term ϵ_t^τ has a zero τ-quantile. β^τ is the coefficient of our interest which represents the impacts of the Bitcoin/gold returns on Y_t, and α^τ measures the influences of the τ-quantile of the first-order temporal-lag of Y_{t-1} on its contemporaneous term. $\beta^\tau(\cdot)$ is assumed to be an unknown function due to the lack of prior information on the relationship. In order to investigate the relationship between the γ-quantile of X_t (X^γ) and τ-quantile of Y_t, we linearize the unknown function $\beta^\tau(\cdot)$ by taking the first-order Taylor expansion around X^γ, which yields the following:

$$\beta^\tau(X_t) = \beta^\tau(X^\gamma) + \beta^{\tau'}(X^\gamma)(X_t - X^\gamma) \equiv b_0(\tau,\gamma) + b_1(\tau,\gamma)(X^\gamma)(X_t - X^\gamma), \tag{11}$$

then we can obtain a new expression of Y_t by substituting Eq. (11) into (10):

$$Y_t = b_0(\tau,\gamma) + b_1(\tau,\gamma)(X^\gamma)(X_t - X^\gamma) + \alpha^\tau Y_{t-1} + \epsilon_t^\tau, \tag{12}$$

Eq. (12) can be solved as:

$$\begin{pmatrix} \widehat{b}_0(\tau,\gamma) \\ \widehat{b}_1(\tau,\gamma) \\ \widehat{\alpha^\tau}(\gamma) \end{pmatrix} = \arg\min_{b_0,b_1,\alpha^\tau} \sum_{t=1}^{T} \rho_\tau[Y_t - b_0 - b_1(X_t - X^\gamma - \alpha^\tau Y_{t-1})]K(\frac{F(X_t)-\gamma}{h}), \qquad (13)$$

where $\rho_\theta(e) = e(\theta I\{e < 0\})$ and $I(\cdot)$ is a indicator function. K is a Gaussian kernel function with bandwidth h. The empirical distribution function is defined as $F(X_t) = 1/T\sum_{i=1}^{T} I(X_i < X_t)$. For the choice of optimal bandwidth h, we employ the cross-validation (CV) method following Duan et al. (2021), which strengthens the robustness of the QQ regression estimates.

3.4. Data

Following extant literature, we collect the daily prices of Bitcoin and gold denominated in US Dollar. We use the Brent crude oil futures price as a proxy for oil price, and two additional variables: the MSCI All Country World Index and the CBOE Crude Oil Volatility Index as proxies for the oil producing companies and expected returns to decompose oil price shocks using the structural vector autoregressive (SVAR) framework of Ready (2018). The whole sample employed in our research covers a total of 1655 observations ranging from January 4, 2016 to January 31, 2023, during which Bitcoin trading has been emerging over time and raised widespread attention (Conlon and McGee, 2020a,b). We consider the log returns of Bitcoin, gold, and oil prices and decompose the oil price returns using the SVAR procedure to obtain s_t, d_t, and r_t.

The summary statistics of the variables are shown in Table 1, and several noteworthy findings emerge. (i).Bitcoin returns are much higher than gold and crude oil, but there is no significant difference in standard deviation, suggesting that Bitcoin has been steadily rising in recent years; (ii).The means and standard deviations of risk shocks are small, which is consistent with the finding that risk shocks in Ready (2018) barely explain changes in oil prices; (iii).The skewness, kurtosis coefficients, and the Jarque-Bera test results indicate that all variables deviate from the normality assumption, which supports the use of QQ method rather than OLS or traditional quantile regression; (iv). The Augmented Dickey-Fuller (ADF) test results ensure the stationarity condition of all series.

4. Empirical results

4.1. Quantile Granger causality analysis

In this section, we employ the causality-in-quantile test to explore the causal relationship between Bitcoin/gold returns and oil price changes/shocks at different quantiles (from q=0.05 to q=0.95). For the analysis, we divide the quantile of the return series into the performance of different market conditions, that is the bear market (from q=0.05 to q=0.45), the normal market (q=0.5) and the bull market (from q= 0.55 to q=0.95). Figures 1, 2 and 3, 4 exhibit the testing results on the series of Bitcoin/gold returns, respectively, in which the test statistic located above the critical value (gray solid line) indicates the Granger causality at 5% significance level under the specific quantile.

First, we focus on the relationship between the Bitcoin market and oil prices/shocks. Figure 1 shows that the causal relationships between Bitcoin returns and changes in oil and identified shocks-except for risk shocks-are in hump-shaped intervals, indicating that the causalities are strongest near normal market conditions and gradually decrease as market conditions become extreme, and illustrating that causality is non-linear and asymmetric. Specifically, according to Figure 1(a), the causal relationship between Bitcoin returns and aggregate level of oil price changes is significant at the 5% level under most quantiles (from q=0.1 to q=0.9), with the strongest predictive power around the median quantile. That is, Bitcoin returns have a more significant impact on oil prices under non-extreme market conditions. The causal relationship between Bitcoin and supply shocks in Figure 1(b) is similar to that in Figure 1(a), where Bitcoin returns are Granger cause of supply shocks from the quantile 0.1 to 0.9. Figure 1(c) shows a weaker causal relationship between Bitcoin and demand shocks, providing insignificant test results under extreme market conditions. Overall, Bitcoin returns are not only Granger causes of oil price changes, but can also predict the supply shocks and demand shocks of oil prices, and there is a consistent mechanism of influence (strongest around normal markets, weaker in bearish and bullish market conditions), but no evident connection with risk shocks (Figure 1(d)). According to Figure 2, statistically, the series of statistics does not exceed the critical value in all scenarios, showing the fact that no Granger cause of the Bitcoin returns in oil price changes and shocks. In other words, oil prices/shocks can not predict Bitcoin returns, either in the aggregate change or in the decomposed shock series. Therefore, the causality-in-quantile test shows that Bitcoin return is a unidirectional Granger cause of oil price changes.

The causality tests between gold returns and oil changes/shocks show similar characteristics to Bitcoin (Figures 3 and 4). According to Figure 3(a) and (b), gold returns are a significant Granger cause of aggregate oil price changes and supply shocks under most market conditions, where they predict supply shocks at all quantiles. In addition, gold is evidently related to demand shocks only under normal market conditions (around q=0.5) and is not connect with the risk shocks. All statistics in Figure 4 are below the 5% critical value, indicating that oil price changes and shocks do not predict the development of the gold market in any market states. In general, gold returns can be a unidirectional Granger cause of aggregate oil price changes and the decomposed supply shocks under all conditions, including extreme market states, while the relations with demand and risk shocks are weak.

Our results can be summarized as that Bitcoin/gold returns have significant impacts on oil changes/shocks. Specifically, Bitcoin and gold have significant unidirectional causality on crude oil price changes, as well as the identified supply and demand shocks. Except for a few extreme market conditions, causality is significant for both oil price and supply shocks, while that to the demand shocks tend to exist mainly under normal market conditions. Moreover, Bitcoin/gold returns do not appear to be linked to the decomposed risk shocks over the data distribution. These findings not only enrich the understanding of the causal relationship between oil prices and Bitcoin/gold markets in different conditions, but also provide new evidence of market correlation from previous research. Since the impact of Bitcoin/gold on oil is unidirectional and irrelevant to risk shock, and exogenous shocks do not significantly alter this pattern of causality, our subsequent empirical quantile-on-quantile analysis will focus on the impact of Bitcoin/gold market on the changes in oil price as well as the decomposed supply shocks and demand shocks, so as to provide a more detailed and specific analysis.

4.2. Quantile-on-quantile (QQ) estimates

To explore the dynamic impact of Bitcoin/gold returns on oil price changes/shocks, the relationships between the different quantiles of returns (from $\tau = 0.1$ to $\tau = 0.9$) was considered. We focus on the estimation results of $b_1(\tau, \gamma)$ in model (12) by QQ method, that is the effect of γ-th quantile of Bitcoin/gold returns on τ-th quantile of oil futures changes/shocks. Figure 5 presents the response surfaces and we are able to find with these results that Bitcoin/gold can serve as a hedge, diversifier or safe haven for oil price and shocks in different market conditions.

Bitcoin and gold returns have different patterns of impact on the aggregate level of oil futures changes (Figure 5 (a) and (b)). Figure 5 (a) plots the effect surface of Bitcoin returns on the oil price changes. Bitcoin returns behave a flat impact pattern on that of crude oil that the impact magnitude is relatively stable and remains as a weakly positive (being less than 0.1) at most of quantiles over the data distribution, indicating weak hedging and diversification capabilities of Bitcoin. The impact turns to become even negative in the particular scenario when both oil and Bitcoin returns are in a bull market ($\tau = \gamma = 0.9$).

Our results are consistent with Selmi et al. (2018) that Bitcoin can act as a hedge, safe haven and diversifier against the oil price fluctuations, but this ability depends on different Bitcoin and oil market conditions. In parallel, gold works differently than Bitcoin under different market states. Figure 5 (b) shows a quasi-monotonic increasing pattern with increases in both of oil and gold quantiles. In specific, the coefficient of gold is negative when the oil price is in a bear market ($\tau = 0.1$, $\tau = 0.15$) and decrease with the strengthen of gold, which indicates that gold acts as a safe haven against the adverse changes of the oil price. As oil price gradually strengthens, the coefficient turns to weakly positive and the role of gold shifts to a diversifier for the oil market, especially when oil prices soar. Our results provide further evidence to existing research that gold is an effective safe haven against adverse oil price movements, but this property is sensitive to oil and gold market conditions.

However, most of the coefficients in Figure 5 (a) (b) are small, indicating that Bitcoin and gold may not play significant roles in hedging, sheltering and diversification for the oil price changes. The potential reason is that the aggregate level of oil price changes are caused by a variety of sources and the impact of Bitcoin/gold on the oil market may be offset by a kinds of shocks, and considering only the impact patterns on the aggregate oil price changes would mask the heterogeneous responses. Therefore, we need to further analyze the response of specific kinds of oil price shocks to the Bitcoin/gold markets. The remaining panels in Figure 9 reflect the impact surfaces of Bitcoin/gold on the identified shocks.

From Figure 5(c), we observe that Bitcoin plays a similar role in the change of supply shocks as it does in the overall change in oil prices. Bitcoin returns have positive coefficients at low levels ($\tau = 0.1$, $\tau = 0.2$), and the impact depicts a decline with increases in quantiles of supply shocks. However, the role of Bitcoin gradually turns to a hedge and safe haven with the simultaneous strengthening of market conditions (both τ and γ increase). As a contrast, demand shocks tend to respond differently to Bitcoin returns than supply shocks. Specifically, Bitcoin returns have negative QQ coefficients when the demand shocks of the oil price is bearish ($\tau = 0.1$, $\tau = 0.15$) or bullish ($\tau = 0.85$, $\tau = 0.9$), showing a sheltering effect that increases as the oil market condition improves, and its impact magnitude is overall equal or less than zero. In the normal markets, the Bitcoin can be used mainly to hedge against oil price shocks. According to the above analysis, the difference in the impact of Bitcoin on supply and demand shocks is mainly reflected in the fact that when both supply and demand shocks are at low levels ($\tau = 0.1$, $\tau = 0.15$, $\tau = 0.2$), Bitcoin can serve as a diversifier for the former and a safe haven for the latter.

Gold returns provide a similar but stronger pattern of impact on supply shocks at different quantiles than it does on the aggregate oil price changes. Specifically, the QQ coefficients of gold returns across market conditions are significant negative when supply shocks are bearish(from $\tau = 0.1$ to $\tau = 0.3$). Different from Figure 5(b), the higher values in coefficients indicates a stronger safe haven role of gold for oil market. As the supply shock of oil strengthens, gold transforms into a hedge and diversifier, and the roles fluctuates dramatically with the market conditions of gold returns. The impact of gold on demand shocks is mainly reflected in hedging and diversification. Figure 5(f) shows that the effect of gold could be relatively highly positive at extremely high quantiles of oil demand shocks, and it declines gradually and even becomes negative at low oil quantiles, indicating the diversifier role of gold in sensitive to the market quantiles. In addition, the coefficients are less than 0 for the normal level demand shocks ($0.2 < \tau < 0.5$), which shows the hedging effect of gold returns.

Combined with the above results, Bitcoin and gold exhibit opposing impact patterns on specific types of oil price changes. For the aggregate level of oil price series, Bitcoin returns behave a flat impact pattern that the impact magnitude remains as a weakly positive at most of quantiles over the data distribution. The impact turns to become even negative in the particular scenario when both oil and Bitcoin returns are bullish. Conversely, the impact of gold returns demonstrates a quasi-monotonic increasing pattern with increases in oil quantiles, and the impact turns to be even negative in oil market depression. The difference between the impact patterns is more evident in the analysis of the decomposed shocks. The diversification role of Bitcoin and the safe haven role of gold are more pronounced at the lower quantiles of supply shocks. For the decomposed oil demand shocks, Bitcoin offers a sheltering effect that increases as the oil market condition improves, while the effect of gold could be relatively highly positive at extremely high quantiles of oil demand shocks. Our results support the findings of the existing literature that both Bitcoin and gold are becoming increasing important and can act as safe havens, hedges, and diversifiers against oil price movements, and these roles are sensitive to market conditions. Furthermore, importantly, we build on the above to derive the dynamic impact of Bitcoin/gold on different sources of oil price volatility, extending the role of Bitcoin and gold to different kinds of investors.

4.3. Additional analysis: the impact of structural breaks

To further examine whether exogenous shocks affect the relationship between Bitcoin/gold and oil, we conduct additional analysis by identifying potential structural breakpoints and then comparing dynamics of the cross-market relationship across sub-samples divided by breakpoints. Based on the methodology by Bai and Perron (1998, 2003), we have conducted the test of structural breaks in the dynamics of oil price returns[2], and have identified two significant breakpoints on March 25, 2020 and February 25, 2022, respectively. The two points correspond to the outbreak of COVID-19 epidemic and the Russia-Ukraine (RU) conflict, two of the most important international events recently occurred that are known to have significant impacts on the world economy. Accordingly, we further divide the whole sample into sub-periods before and after the specified breakpoints, i.e., the epidemic onset and the RU conflict, respectively. To further eliminate the impact of other potential exogenous shocks

[2]Estimation of the Bitcoin and gold return series yields similar structural breaks to that of oil returns.

within sub-samples, we have followed Becker et al. (2021) by demeaning the data within each sub-period, in order to ensure that the break of the whole sample is only due to the above two exogenous events. Both the causality-in-quantiles test and quantile-on-quantile method are employed in each sub-sample to analyze the dynamics of the cross-market relationship before and after the pandemic onset and the RU conflict, respectively.

As for the analysis of causality, we first focus on the event of the COVID-19 pandemic outbreak on 12 March, 2020 and examine the Granger causality between oil and Bitcoin/gold in two sub-periods from January 4, 2016 to March 12, 2020 (before the COVID-19 epidemic) and from March 13, 2020 to January 31, 2023 (after the COVID-19 epidemic), respectively.[3] Figure 6 shows the causality from Bitcoin/gold to the oil price return before and after COVID-19 epidemic. The causal relationship between Bitcoin and oil prices before COVID-19 epidemic also shows a hump-shaped interval, but under extreme market conditions ($q<0.25$, $q>0.8$), the causal relationship is insignificant at the 5% level. After the outbreak of COVID-19 epidemic, the pattern of causality changes, and the effect of Bitcoin on oil is significant in bear markets, while it remains insignificantly linked in bull markets, suggesting that after COVID-19 epidemic Bitcoin is gradually able to influence price changes in oil market downturns. The causality tests between gold returns and oil changes both before and after the COVID-19 epidemic show similar characteristics to Bitcoin (as shown in Figures 6(a) and (b)), with gold exhibiting a significant impact on the oil market during bear markets after COVID-19 epidemic. In contrast, Figure 7 shows that changes in oil prices do not Granger cause that in Bitcoin and gold returns in both sub-periods.

Regarding the RU conflict with the start date identified as February 24, 2022, we accordingly examine the causality between oil and Bitcoin/gold in the two sub-periods of pre-

[3] As of March 11, 2020, more than 11,800 cases had been reported in 114 countries, with the COVID-19 was categorized as a "pandemic". Our estimate of breaks is quite close to this date.

and post-conflict,[4] and obtain results similar to those in the above analysis of COVID-19 epidemic. Figure 8 shows Bitcoin/gold has a hump-shaped effect on oil prices, with causality being strongest under normal market conditions and weakening as the market becomes extreme. Following the outbreak of the RU conflict, Bitcoin/gold is able to have a significant impact on oil prices during market downturns, while the causal relationship with oil remains weak during bullish markets. In turn, oil prices are found to have no Granger causal impact on Bitcoin/gold returns in any market condition changes (as shown in Figure 9).

Moreover, the causality analysis shows that exogenous shocks do not change the unidirectional causality pattern that Bitcoin/gold has for oil market, which allows us to explore whether there are differences in the safe haven and hedging effects of Bitcoin/gold on the oil market over different time periods. Figures 10 and 11 present the corresponding QQ estimation of the impact of Bitcoin/gold on oil price returns before and after COVID-19 and the RU conflict, respectively, over the joint data distribution of both dependent and independent variables. Specifically, according to Figure 10 (a) and (c), Bitcoin mainly manifests a flat hedging and diversification effect on the oil market before the COVID-19, while gold played a significant safe haven role with a negative coefficient during the oil market downturn. These roles are maintained until after COVID-19, but fluctuated dramatically as market conditions changed and the magnitude of the impact changed to some extent (as shown in Figure 10 (b) and (d)). At the same time, Figure 11 (a) and (c) show that Bitcoin and gold also exhibit flat patterns of influence prior to the RU conflict, play the roles of diversification and safe haven, respectively. The exogenous shock generated by the RU conflict (as shown in Figure 10 (b) and (d)) does not significantly alter the role under extreme oil markets, but rather enhances the impact coefficient under normal conditions (around q=0.5), transforming the previous hedging role of Bitcoin and gold into diversified assets. We can thus conclude that

[4] On February 24, 2022 Russian President Vladimir Putin declared an all-out war against Ukraine. Our estimate of breaks corresponds almost perfectly to this date.

Bitcoin generally demonstrates a hedging and diversification role for the oil market, while gold is able to provide a safe haven effect. These patterns have not changed intrinsically as a result of exogenous shocks, but rather in magnitude.

The above results suggest that neither the COVID-19 outbreak nor the RU conflict essentially has changed the causal relationships and QQ impact patterns between Bitcoin/gold and oil prices; instead, these events appear to only slightly alter the impact magnitude on the oil market and the range of market conditions[5]. This further validates that Bitcoin/gold only features a significant unidirectional causal relationship with oil changes. Movever, Bitcoin/gold can act as safe havens, hedges, and diversifiers against oil price movements, and these roles are sensitive to market conditions. Bitcoin mainly serves as a diversifier while gold acts as a shelter when the oil prices are bearish. Noteworthy, this section excludes the impact of other exogenous shocks on the estimation, such as the multi-wave climax of COVID-19 after its outbreak, and yields results consistent with the full sample, supporting the robustness of the empirical analysis in this paper.

4.4. Contextualization of results

We discuss in this subsection the link between our results and the extant relevant literature in terms of estimation strategy and theoretical interpretation, and through this we summarize the corresponding implications and enlightenment. Despite the large number of extant studies on the performance of Bitcoin/gold in response to financial and commodity market turmoil, especially in the oil market, most empirical results are inconsistent.

Specifically, for the traditionally known hedging and sheltering asset, Baur and Lucey (2010) found that gold could serve as a hedge and effective safe haven for European and US stock markets, but could not mitigate bond uncertainty in these economies. Conversely, Ciner

[5]We have also considered the oil shocks and the results show that the sub-periods exhibit causality and QQ impact patterns consistent with the full sample, with exogenous shocks not inherently changing the relationship between Bitcoin/gold and oil shocks.

et al. (2013) pointed to gold's role as a shelter for stock markets, bonds, and the US dollar, but not as a safe haven for oil markets, while Reboredo (2013) suggested gold as an effective safe haven for oil price volatility, but not as a hedge against adverse changes in oil prices. On the other hand, studies on the hedging and safe haven effects of Bitcoin have been diverse in recent years. Baur et al. (2015) argued that Bitcoin does not correlate well with price movements in stocks, bonds, and commodities under different market conditions. Dyhrberg (2016) found hedging properties of Bitcoin, which can be incorporated into portfolios to reduce the adverse effects of market volatility. Bouri et al. (2017b) indicated that Bitcoin served as hedge and safe haven for commodity markets, but these effects disappeared after the December 2013 Bitcoin price crash and showed only weak diversification gains for non-energy commodity indices. Bouri et al. (2018), however, demonstrated that Bitcoin was a safe asset under conditions of financial turmoil. Selmi et al. (2018) argue that both Bitcoin and gold can act as a safe haven, hedge, and diversifier for oil price volatility, but these effects depend on whether Bitcoin, gold, and oil prices are on the downside, normal, or upside, and their empirical evidence suggests that the differences in the impact patterns of Bitcoin/gold on the oil market are nuanced.

It can be summarized that this paper enriches the existing literature from the following aspects. First, Bitcoin/gold is found to be a unidirectional Granger cause of the oil market, with stronger heterogeneity in normal market conditions and weaker heterogeneity in extreme market conditions. Second, using the more comprehensive and robust evaluation strategy QQ methodology, it is concluded that Bitcoin/gold can be used as a safe haven, hedge or diversifier for oil market fluctuations. However, these patterns of influence are sensitive to the market conditions under which Bitcoin, gold and oil markets evolve, with Bitcoin/gold playing significantly different roles. For example, high data quantiles of gold act as a hedge during oil bear markets and shift to a diversification role during gold market downturns, while Bitcoin's diversification role on low quantiles of oil prices disappears as the bitcoin market strengthens.

Third, the results regarding structural breaks suggest that exogenous shocks from both the COVID-19 pandemic and the RU conflict do not inherently change the pattern of the relationship between Bitcoin/gold and oil. Fourth, we employ the model in Ready (2018) to decompose oil price changes into supply, demand, and risk shocks. After confirming that there is no association between Bitcoin/gold returns and risk shocks, the main analysis focuses on the pattern of Bitcoin/gold effects on oil price supply and demand shocks. The findings suggest that Bitcoin can serve as a hedge and diversification tool for supply shocks, while exhibiting the function of hedging and masking demand shocks. At the same time, gold is an effective safe haven against supply shocks and can also serve as a hedging and diversification tool during normal and bullish market phases, rather than providing a safe haven for demand shocks.

The potential mechanisms leading to the above four impact patterns can be explained as follows. First, the paper argues that the heterogeneous causality reflects the importance of managing asset price tail risk (As in Shahzad et al., 2019). It is difficult to link oil to other assets during market downturns or high tides, making it necessary for investors to find safe havens and hedges for oil assets to reasonably mitigate losses in abnormal conditions. Second, the differential impact patterns of Bitcoin and gold may be attributed to the difference in the nature of the two assets. Although Bitcoin is known as digital gold, it is less mature than gold, has higher uncertainty (Lucey et al., 2022), and all of Bitcoin's characteristics can be replicated by issuing a similar coin with a similar or different name, whereas gold cannot be replicated (Baur and Hoang, 2021). These differences would make their similarity not acceptable to investors, resulting in Bitcoin and gold playing different roles. Third, the pattern of Bitcoin/gold impact on oil is found to be stable over time and against exogenous shocks. In the aftermath of international events such as COVID-19 and the RU conflict, market relationships may change briefly and then recover quickly, and exogenous shocks may alter the magnitude of Bitcoin/gold's impact on the oil market, but not inherently change its role. Fourth, the heterogenous impact patterns of oil shocks reveal differences in the behavior of different types of investors. Following Ready (2018), supply shocks are mainly manifested as oil price changes due to the production and supply capacity of oil-producing countries, while demand shocks are mainly caused by demand changes for oil in economic sectors, including manufacturing, oil-intensive and consumer industries. Therefore, different types of market investors can take advantage of the dynamic and asymmetric relationship between the Bitcoin/gold and oil markets by choosing different effective shelters and hedges. Investors, being interested in oil-related investments, can add Bitcoin to their portfolios to reduce their risk during oil market downturns, while gold is primarily a better hedging asset for oil producers. In addition, both Bitcoin and gold can serve as hedging and diversification assets for both supply-side and demand-side investors, with gold offering more significant diversification benefits.

In summary, we provide empirical evidence that Bitcoin/gold exhibits different patterns of hedging and sheltering effects in oil-related assets, and these patterns tend to be stable when facing exogenous shocks over time. When oil prices fall, only gold can protect against oil price fluctuations. Both Bitcoin and gold can serve as hedges and diversifiers against oil when the markets boom. For supply shocks, Bitcoin's diversification role and gold's hedging role are more pronounced, while the opposite is true for oil price demand shocks with Bitcoin serving as a hedge and gold playing more of a hedging and diversification asset role. The theoretical significance of the empirical finding is that it not only complements the research on the hedging and safe-haven effects of Bitcoin/gold on the oil market, but also explains the potential reasons for the inconsistent results of existing studies. In addition, it provides updated evidence to examine whether the role of Bitcoin/gold changes before and after the COVID-19 and the RU conflict. The practical implications regarding our obtained results are to provide recommendations for oil market investors with effective risk management of their oil-related portfolios. At the same time, it can help policymakers to have a clear understanding of the effective investment shelters for various oil price shocks under various conditions to sustain healthy economic performance and financial stability.

4.5. Robustness Checks

To ensure the robustness of our main findings, we conduct a series of additional analysis such as alternative estimation techniques, and variable selection to compare with the benchmark results.

4.5.1. Alternative Granger causality test

We have employed the non-parametric wavelet-based Granger causality (NWGC) test developed by Chen et al. (2006) and Dhamala et al. (2008) as a robustness check of the causality between Bitcoin/gold and oil/shocks obtained by causality-in-quantiles test. The NWGC test is able to capture all spectral features of the data series, thus providing causality between variables at different time scales. It has been widely confirmed as an appropriate tool for testing causal relationships between financial series(Benhmad, 2012; Bouri et al., 2017a; Torun et al., 2020), and is helpful for different types of market traders having different investment horizons.

Table 2 reports the results of the NWGC test between Bitcoin/gold and oil/shocks. The NWGC test gives the frequencies corresponding to Granger causality in the respective directions, and the inverse of the frequency is the cycle length, which shows the range of trading days that exhibit Granger causality. Table 2 shows that Bitcoin/gold has a significant causal relationship with oil and shocks. The frequency in the direction from Bitcoin to oil returns and shocks varies from 0.01 to 0.02 or greater than 0.06. This suggests that Bitcoin has a significant impact on the oil market in both the short and long terms, ranging from less than 16 days and 50-100 days. On the other hand, oil and shocks are found to exert no impact on Bitcoin returns across any frequencies. Gold exhibits similar test results to Bitcoin, showing predictive performance in the oil market over a large range of time scales, while the difference between the role of gold and Bitcoin is that oil can also exert impacts on the gold market over a longer period of time but not on the Bitcoin market.

The results of the NWGC test can be summarized as follows. Bitcoin behaves as a unidirectional Granger cause of oil returns and specific shocks and this relationship exists in the short and long term, gold is also able to influence changes in oil returns and shocks, while oil in turn is only able to predict the gold market in the long term. These results are generally consistent with the pattern presented by the quantile causality test.

4.5.2. Alternative quantile estimation strategy

According to Sim and Zhou (2015), the QQ method can be regarded as a decomposition of the traditional quantile regression(QR), so we follow Duan et al. (2021) and compare the γ-averaged of the QQ estimates with the traditional QR estimates to check the robustness of the QQ method results, where the γ-averaged of the QQ estimates can be defined as

$$\theta_1(\tau) \equiv \overline{\hat{b}_1(\tau)} = \frac{1}{n} \sum_{\gamma} \hat{b}_1(\tau, \gamma), \tag{14}$$

where n is the number of grid points for γ. Figure 12 gives the QR and γ-averaged QQ estimates for Bitcoin and gold on oil prices and identified shocks, and some noteworthy results emerge.

First, the γ-averaged QQ estimates are close to the QR results in most states in terms of numerical and economic significance. In a few conditions, such as the γ-averaged QQ coefficient of Bitcoin on supply shocks at $\tau = 0.85$ is 0.03, while the QR estimate is 0.07, with large numerical differences, but both suggest a diversified impact for Bitcoin to supply shocks. Second, the similar QQ and QR coefficients further validate the conclusion in previous section that Bitcoin can be used as a diversifier for supple shock when it is bearish, and acts as a safe haven against demand shocks, while gold produces the opposite pattern of impact against oil price shocks as Bitcoin.

Thus, the analysis in this section not only shows that the key features of QR models can be recovered by summarizing the more disaggregated information contained in the QQ estimates, but also further validates our exploration of the safe haven, hedging, and diversification roles of bitcoin and gold.

4.5.3. Alternative variable selection

In addition to using the QR regression as an alternative estimation strategy, we re-estimate the QQ coefficients by replacing the main variables under consideration as another robustness check. Specifically, for proxy of oil prices, the WTI crude oil futures price series is used in place of the early used Brent crude oil futures, for expected returns, the CBOE Crude Oil Volatility Index (OVX) is replaced by the CBOE Volatility Index(VIX). We control for a sample interval of January 4, 2016 to January 31, 2023, consistent with that in the main analysis.

Figure 13 presents the QQ results of the re-estimation after replacing the price series. For the price of WTI crude oil futures, Bitcoin returns show a decreasing impact pattern with increasing market quantile of Bitcoin when oil market is bearish, while the coefficients are significantly negative when both are bullish (Figure 13 (a)); gold shows a safe haven effect and stronger diversification (Figure 13 (b)). These surfaces of impact are consistent with the results of the analysis using Brent crude oil futures. The patterns of the effects of Bitcoin/gold on identified shocks are also very similar to the estimates from the original data. The main roles of Bitcoin on the re-decomposed supply shocks are diversifier and hedging (Figure 13 (c)), while it reflects a sheltering role on demand shocks (Figure 13 (e)). In parallel, gold can act as a safe haven, hedging and diversification asset for supply shocks (Figure 13 (d)), while it mainly delivers hedging and diversification effects on demand shocks (Figure 13 (f)). Thus, the estimated impact of using a series of alternative variables is generally consistent with the earlier analysis, further supporting the reliability of the empirical findings of this paper.

5. Conclusion

While there exists widespread attention on the relationship of Bitcoin with financial assets and commodities, oil-related assets in particular, no consensus has been made that might be due to the following limitations. First, simply relying on the aggregate data might mask or even bias the law of oil price dynamics driven by shocks from various sources. Accordingly, potential difference of the effectiveness of the sheltering role of Bitcoin in the face of oil price shocks from perspectives of the demand, supply, and risk is neglected. Second, there exists little in-depth research on studying the non-linearity and asymmetry of the causality and then the market relationship between Bitcoin and oil across market conditions.

This paper therefore fills the gap by studying the sheltering role of Bitcoin for various decomposed oil shocks within a quantile-based framework. In specific, we decompose oil price changes into supply, demand, and risk-driven shocks by employing the method recently developed by Ready (2018). Next, we use a non-parametric causality-in-quantiles test to study the causal relationships between Bitcoin/gold and the oil shocks under different market conditions. The investment sheltering role of Bitcoin with a comparison of gold is further explored in a full-distribution environment built by a quantiles-on-quantiles method.

Our findings are summarized as follows. The causality is unidirectional that is from Bitcoin/gold to various oil shocks. Both Bitcoin and gold can generally serve as investment shelters against adverse oil price fluctuations. Such roles tends to be sensitive across different quantiles and different types of oil shocks, while being unchanged in the face of shocks from exogenous events. The sheltering role of gold is found to be greater than that of Bitcoin for the supply shock, while the results reverse for the demand shock. Specifically, Bitcoin serves as a diversifier when oil prices are bearish, while gold acts as a shelter against oil volatility. Conversely, when oil prices are at high levels, Bitcoin returns are negatively correlated with oil price changes, while the role of gold shifts to be a diversifier. In relatively normal market conditions, both Bitcoin and gold can help hedge against oil price volatility. The difference in the roles tends to become more pronounced in the analysis of decomposition shocks. The diversification role of Bitcoin and the safe haven effect of gold are more pronounced in lower quantiles of supply shocks, and they have opposite effects on demand-side oil price shocks with Bitcoin being as a safe haven and gold acting as a hedge. A series of alternative analyses ensures the robustness of our findings.

Our findings possess practical implications for selection of an effective investment shelter against oil depression that is from different sources including the demand, supply, and risk perspectives of crude oil. Primarily, the effects of Bitcoin/gold on adverse movements in oil prices exhibit distinct patterns as market conditions change and varying with sources of price shocks. This suggests that market investors should choose an effective shelter that is applicable for different conditions based on information about the asymmetric relationship between Bitcoin/gold and oil. In particular, for different types of oil price shocks, investors and practitioners from the supply side notably including the oil producers can add gold to their portfolios to mitigate risk during oil market downturns. At the same time, Bitcoin is found to be a more effective shelter for demand-side investors mainly including manufacturing, oil-intensive and consumer industries. As for policymakers, clear comprehension of the investment shelters against oil-related fluctuations under various market conditions contributes to the stabilization of the oil market operations, resulting in healthy economic performance and financial stability.

References

Ahmadi, M., Behmiri, N. B., and Manera, M. (2016), "How is volatility in commodity markets linked to oil price shocks?" *Energy Economics*, 59, 11–23.

Akhtaruzzaman, M., Boubaker, S., Lucey, B. M., and Sensoy, A. (2021), "Is gold a hedge or a safe-haven asset in the COVID–19 crisis?" *Economic Modelling*, 102, 105588.

Al-Khazali, O., Elie, B., Roubaud, D., et al. (2018), "The impact of positive and negative macroeconomic news surprises: Gold versus Bitcoin," *Economics Bulletin*, 38, 373–382.

Al-Nassar, N. S., Boubaker, S., Chaibi, A., and Makram, B. (2022), "In search of hedges and safe havens during the COVID 19 pandemic: Gold versus Bitcoin, oil, and oil uncertainty," *The Quarterly Review of Economics and Finance*.

Bahloul, W., Balcilar, M., Cunado, J., and Gupta, R. (2018), "The role of economic and financial uncertainties in predicting commodity futures returns and volatility: Evidence from a nonparametric causality-in-quantiles test," *Journal of Multinational Financial Management*, 45, 52–71.

Bai, J. and Perron, P. (1998), "Estimating and testing linear models with multiple structural changes," *Econometrica*, 47–78.

— (2003), "Computation and analysis of multiple structural change models," *Journal of applied econometrics*, 18, 1–22.

Balcilar, M., Bekiros, S., and Gupta, R. (2017), "The role of news-based uncertainty indices in predicting oil markets: a hybrid nonparametric quantile causality method," *Empirical Economics*, 53, 879–889.

Balcilar, M., Gupta, R., Kyei, C., and Wohar, M. E. (2016), "Does economic policy uncertainty predict exchange rate returns and volatility? Evidence from a nonparametric causality-in-quantiles test," *Open Economies Review*, 27, 229–250.

Balcilar, M., Gupta, R., Pierdzioch, C., and Wohar, M. E. (2018), "Terror attacks and stock-market fluctuations: Evidence based on a nonparametric causality-in-quantiles test for the G7 countries," *The European Journal of Finance*, 24, 333–346.

Baur, D. G. and Hoang, L. (2021), "The Bitcoin gold correlation puzzle," *Journal of Behavioral and Experimental Finance*, 32, 100561.

Baur, D. G., Hong, K., and Lee, A. D. (2018), "Bitcoin: Medium of exchange or speculative assets?" *Journal of International Financial Markets, Institutions and Money*, 54, 177–189.

Baur, D. G., Lee, A. D., and Hong, K. (2015), "Bitcoin: currency or investment?" *Available at SSRN*, 2561183.

Baur, D. G. and Lucey, B. M. (2010), "Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold," *Financial review*, 45, 217–229.

Becker, J., Hollstein, F., Prokopczuk, M., and Sibbertsen, P. (2021), "The memory of beta," *Journal of Banking & Finance*, 124, 106026.

Benhmad, F. (2012), "Modeling nonlinear Granger causality between the oil price and US dollar: A wavelet based approach," *Economic modelling*, 29, 1505–1514.

Bouoiyour, J. and Selmi, R. (2015), "What does Bitcoin look like?" *Annals of Economics & Finance*, 16.

— (2017), "The Bitcoin price formation: Beyond the fundamental sources," *arXiv preprint arXiv:1707.01284*.

Bouri, E., Gupta, R., Lau, C. K. M., Roubaud, D., and Wang, S. (2018), "Bitcoin and global financial stress: A copula-based approach to dependence and causality in the quantiles," *The Quarterly Review of Economics and Finance*, 69, 297–307.

Bouri, E., Gupta, R., Tiwari, A. K., and Roubaud, D. (2017a), "Does Bitcoin hedge global uncertainty? Evidence from wavelet-based quantile-in-quantile regressions," *Finance Research Letters*, 23, 87–95.

Bouri, E., Jalkh, N., Molnár, P., and Roubaud, D. (2017b), "Bitcoin for energy commodities before and after the December 2013 crash: diversifier, hedge or safe haven?" *Applied Economics*, 49, 5063–5073.

Bouri, E., Molnár, P., Azzi, G., Roubaud, D., and Hagfors, L. I. (2017c), "On the hedge and safe haven properties of Bitcoin: Is it really more than a diversifier?" *Finance Research Letters*, 20, 192–198.

Chatziantoniou, I., Filippidis, M., Filis, G., and Gabauer, D. (2021), "A closer look into the global determinants of oil price volatility," *Energy Economics*, 95, 105092.

Chemkha, R., BenSaïda, A., Ghorbel, A., and Tayachi, T. (2021), "Hedge and safe haven properties during COVID-19: Evidence from Bitcoin and gold," *The Quarterly Review of Economics and Finance*, 82, 71–85.

Chen, Y., Bressler, S. L., and Ding, M. (2006), "Frequency decomposition of conditional Granger causality and application to multivariate neural field potential data," *Journal of neuroscience methods*, 150, 228–237.

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., and Sovacool, B. (2018), "Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework," *Energy Research & Social Science*, 37, 175–190.

Chua, J. H., Sick, G., and Woodward, R. S. (1990), "Diversifying with gold stocks," *Financial Analysts Journal*, 46, 76–79.

Ciner, C. (2001), "On the long run relationship between gold and silver prices A note," *Global finance journal*, 12, 299–303.

Ciner, C., Gurdgiev, C., and Lucey, B. M. (2013), "Hedges and safe havens: An examination of stocks, bonds, gold, oil and exchange rates," *International Review of Financial Analysis*, 29, 202–211.

Conlon, T., Lucey, B. M., and Uddin, G. S. (2018), "Is gold a hedge against inflation? A wavelet time-scale perspective," *Review of Quantitative Finance and Accounting*, 51, 317–345.

Conlon, T. and McGee, R. (2020a), "Safe haven or risky hazard? Bitcoin during the COVID-19 bear market," *Finance Research Letters*, 35, 101607.

Conlon, T. and McGee, R. J. (2020b), "Betting on Bitcoin: Does gambling volume on the blockchain explain Bitcoin price changes?" *Economics Letters*, 191, 108727.

Das, D., Le Roux, C. L., Jana, R. K., and Dutta, A. (2020), "Does Bitcoin hedge crude oil implied volatility and structural shocks? A comparison with gold, commodity and the US Dollar," *Finance Research Letters*, 36, 101335.

Demir, E., Gozgor, G., Lau, C. K. M., and Vigne, S. A. (2018), "Does economic policy uncertainty predict the Bitcoin returns? An empirical investigation," *Finance Research Letters*, 26, 145–149.

Dhamala, M., Rangarajan, G., and Ding, M. (2008), "Estimating Granger causality from Fourier and wavelet transforms of time series data," *Physical review letters*, 100, 018701.

Disli, M., Nagayev, R., Salim, K., Rizkiah, S. K., and Aysan, A. F. (2021), "In search of safe haven assets during COVID-19 pandemic: An empirical analysis of different investor types," *Research in International Business and Finance*, 58, 101461.

Duan, K., Ren, X., Shi, Y., Mishra, T., and Yan, C. (2021), "The marginal impacts of energy prices on carbon price variations: Evidence from a quantile-on-quantile approach," *Energy Economics*, 95, 105131.

Dutta, A., Das, D., Jana, R., and Vo, X. V. (2020), "COVID-19 and oil market crash: Revisiting the safe haven property of gold and Bitcoin," *Resources Policy*, 69, 101816.

Dyhrberg, A. H. (2016), "Hedging capabilities of bitcoin. Is it the virtual gold?" *Finance Research Letters*, 16, 139–144.

Fattouh, B. and Economou, A. (2020), "Oil Supply Shock in the time of the Coronavirus," *Oxford Institute for Energy Studies*, 30.

Ghasemian, S., Faridzad, A., Abbaszadeh, P., Taklif, A., Ghasemi, A., and Hafezi, R. (2020), "An overview of global energy scenarios by 2040: identifying the driving forces using cross-impact analysis method," *International Journal of Environmental Science and Technology*, 1–24.

Hamilton, J. D. (2009), "Understanding crude oil prices," *The energy journal*, 30.

Herrera, A. M., Karaki, M. B., and Rangaraju, S. K. (2019), "Oil price shocks and US economic activity," *Energy policy*, 129, 89–99.

Hillier, D., Draper, P., and Faff, R. (2006), "Do precious metals shine? An investment perspective," *Financial Analysts Journal*, 62, 98–106.

Jeong, K., Härdle, W. K., and Song, S. (2012), "A consistent nonparametric test for causality in quantile," *Econometric Theory*, 28, 861–887.

Ji, Q., Zhang, D., and Zhao, Y. (2020), "Searching for safe-haven assets during the COVID-19 pandemic," *International Review of Financial Analysis*, 71, 101526.

Kang, S. H., McIver, R. P., and Hernandez, J. A. (2019), "Co-movements between Bitcoin and Gold: A wavelet coherence analysis," *Physica A: Statistical Mechanics and its Applications*, 536, 120888.

Kaul, A. and Sapp, S. (2006), "Y2K fears and safe haven trading of the US dollar," *Journal of international money and finance*, 25, 760–779.

Kilian, L. (2008), "The economic effects of energy price shocks," *Journal of economic literature*, 46, 871–909.

Kilian, L. and Lewis, L. T. (2011), "Does the Fed respond to oil price shocks?" *The Economic Journal*, 121, 1047–1072.

Le, T.-H., Le, A. T., and Le, H.-C. (2021), "The historic oil price fluctuation during the Covid-19 pandemic: What are the causes?" *Research in International Business and Finance*, 58, 101489.

Lee, C.-C., Lee, C.-C., and Ning, S.-L. (2017), "Dynamic relationship of oil price shocks and country risks," *Energy Economics*, 66, 571–581.

Lucey, B. M., Vigne, S. A., Yarovaya, L., and Wang, Y. (2022), "The cryptocurrency uncertainty index," *Finance Research Letters*, 45, 102147.

Luther, W. J. and Salter, A. W. (2017), "Bitcoin and the bailout," *The Quarterly Review of Economics and Finance*, 66, 50–56.

Malik, F. and Umar, Z. (2019), "Dynamic connectedness of oil price shocks and exchange rates," *Energy Economics*, 84, 104501.

Naeem, M. A., Hasan, M., Arif, M., Suleman, M. T., and Kang, S. H. (2022), "Oil and gold as a hedge and safe-haven for metals and agricultural commodities with portfolio implications," *Energy Economics*, 105, 105758.

Raheem, I. D. (2021), "COVID-19 pandemic and the safe haven property of Bitcoin," *The Quarterly Review of Economics and Finance*, 81, 370–375.

Ready, R. C. (2018), "Oil prices and the stock market," *Review of Finance*, 22, 155–176.

Reboredo, J. C. (2013), "Is gold a safe haven or a hedge for the US dollar? Implications for risk management," *Journal of Banking & Finance*, 37, 2665–2676.

Ren, X., Wang, R., Duan, K., and Chen, J. (2022), "Dynamics of the sheltering role of Bitcoin against crude oil market crash with varying severity of the COVID-19: A comparison with gold," *Research in International Business and Finance*, 62, 101672.

Selmi, R., Mensi, W., Hammoudeh, S., and Bouoiyour, J. (2018), "Is Bitcoin a hedge, a safe haven or a diversifier for oil price movements? A comparison with gold," *Energy Economics*, 74, 787–801.

Shahzad, S. J. H., Bouri, E., Roubaud, D., Kristoufek, L., and Lucey, B. (2019), "Is Bitcoin a better safe-haven investment than gold and commodities?" *International Review of Financial Analysis*, 63, 322–330.

Sim, N. and Zhou, H. (2015), "Oil prices, US stock return, and the dependence between their quantiles," *Journal of Banking & Finance*, 55, 1–8.

Smales, L. A. (2019), "Bitcoin as a safe haven: Is it even worth considering?" *Finance Research Letters*, 30, 385–393.

Torun, E., Chang, T.-P., and Chou, R. Y. (2020), "Causal relationship between spot and futures prices with multiple time horizons: A nonparametric wavelet Granger causality test," *Research in International Business and Finance*, 52, 101115.

Uddin, G. S., Rahman, M. L., Shahzad, S. J. H., and Rehman, M. U. (2018), "Supply and demand driven oil price changes and their non-linear impact on precious metal returns: A Markov regime switching approach," *Energy Economics*, 73, 108–121.

Upper, C. (2000), "How Safe was the'Safe Haven'? Financial Market Liquidity during the 1998 Turbulences," .

Wang, G.-J., Xie, C., Wen, D., and Zhao, L. (2019), "When Bitcoin meets economic policy uncertainty (EPU): Measuring risk spillover effect from EPU to Bitcoin," *Finance Research Letters*, 31.

Wang, Y., Lucey, B., Vigne, S. A., and Yarovaya, L. (2022), "An index of cryptocurrency environmental attention (ICEA)," *China Finance Review International*.

Wen, F., Tong, X., and Ren, X. (2022), "Gold or Bitcoin, which is the safe haven during the COVID-19 pandemic?" *International Review of Financial Analysis*, 81, 102121.

Wu, S., Tong, M., Yang, Z., and Derbali, A. (2019), "Does gold or Bitcoin hedge economic policy uncertainty?" *Finance Research Letters*, 31, 171–178.

Table 1: Descriptive statistics

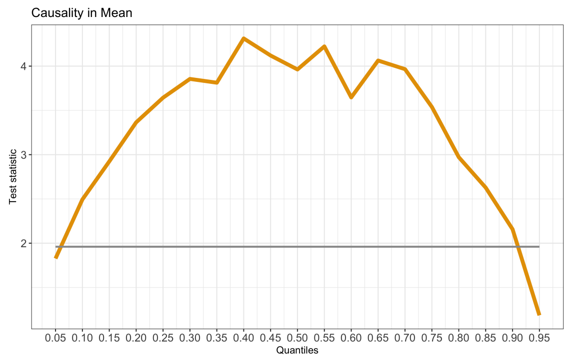
	Mean	Median	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	ADF
Bitcoin	0.271	0.14	4.265	-0.157	7.029	3425***	-10.79***
Gold	0.039	0.04	0.878	-0.017	6.688	3095***	-11.35***
Oil	0.088	0.23	2.610	-0.497	14.890	15041***	-12.69***
s_t	0.124	0.315	4.362	-2.049	25.924	47627***	-12.30***
d_t	-0.033	-0.096	1.697	1.824	27.852	54556***	-11.27***
r_t	-0.003	-0.050	0.684	5.894	207.045	2972932***	-11.57***

Note: (i)Calculations for Bitcoin, gold and oil are based on logarithmic yields; (ii)The Jarque-Bera (JB) statistics test for the null hypothesis of normality; (iii)The ADF test reports unit root test results with the null hypothesis of non-stationarity. (iv)*,** and *** represent the 10%, 5% and 1% significance level respectively.

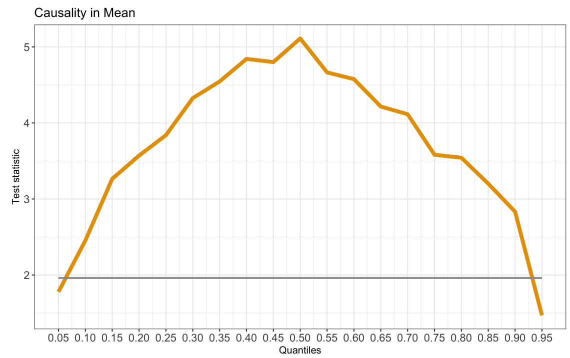
Table 2: Results of nonparametric wave-based Granger causality testing

	Bitcoin→Oil/shocks		Oil/shocks→Bitcoin	
	Frequency	Cycle Length	Frequency	Cycle Length
oil return	0.01-0.02, 0.1↑	50-100, 10↓	/	/
supply shock	0.01-0.02, 0.06↑	50-100, 16↓	/	/
demand shock	0.03-0.1	10-33	/	/
risk shock	0.01-0.02	50-100	/	/
	Gold→Oil/shocks		Oil/shocks→Gold	
	Frequency	Cycle Length	Frequency	Cycle Length
oil return	0.01-0.015, 0.05↑	66-100, 20↓	0.01-0.012	83-100
supply shock	0.01-0.02, 0.1↑	50-100, 10↓	0.01-0.011	90-100
demand shock	0.01-0.02, 0.08↑	50-100, 13↓	0.01-0.012	83-100
risk shock	0.015-0.02	50-66	/	/

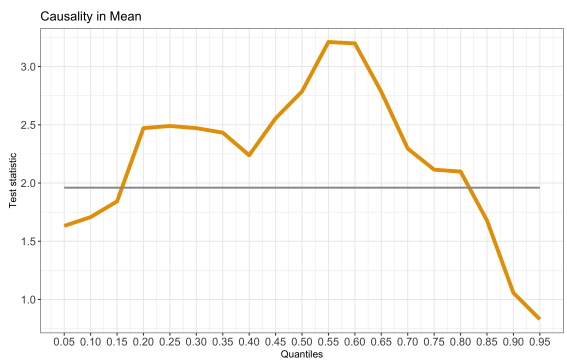
Note: (i)Bitcoin(Gold) → oil/shocks denotes unidirectional causality from Bitcoin(Gold) to oil/shocks, oil/shocks → Bitcoin(Gold) denotes unidirectional causality from oil/shocks to Bitcoin(Gold); (ii)Frequency refers to the cycle per trading day and Cycle Length is the trading days; (iii)↑ means 'equal and higher than' and ↓ means 'equal and less than'.



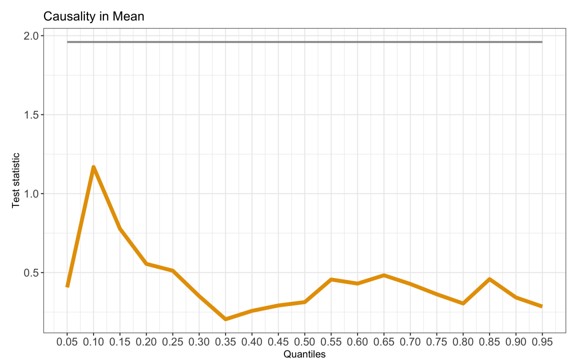
(a) Bitcoin to oil futures



(b) Bitcoin to supply shock

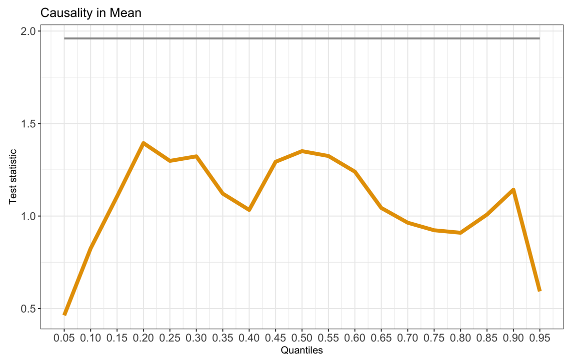


(c) Bitcoin to demand shock

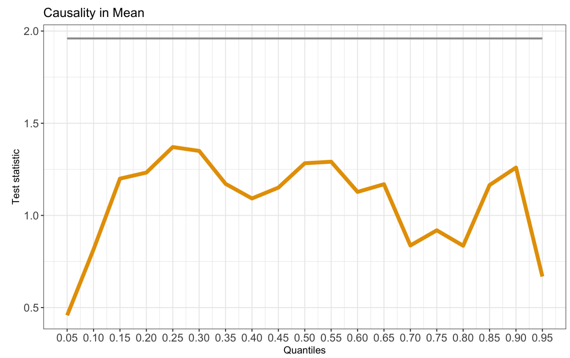


(d) Bitcoin to risk shock

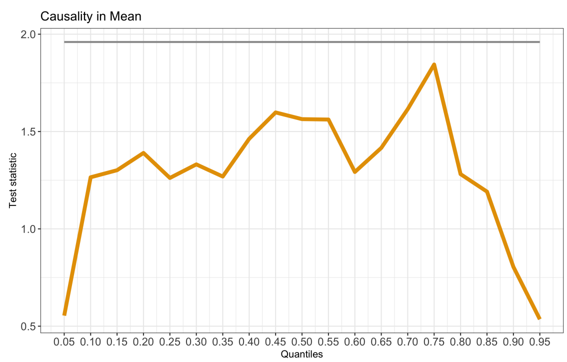
Figure 1: Causality-in-quantile test results of the Bitcoin price return on the oil futures change and shocks. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



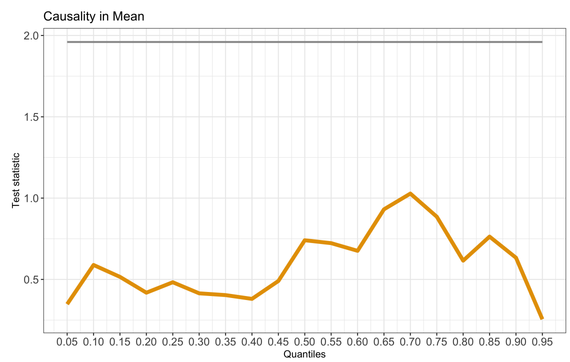
(a) Oil futures to Bitcoin



(b) Supply shock to Bitcoin

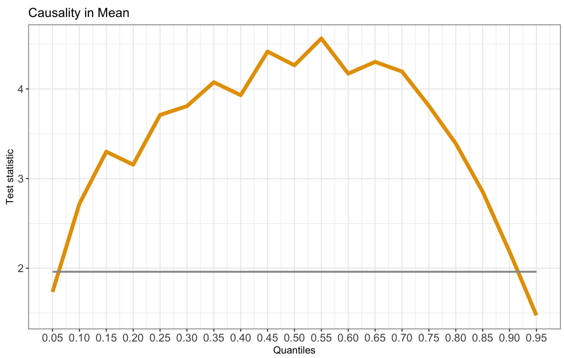


(c) Demand shock to Bitcoin

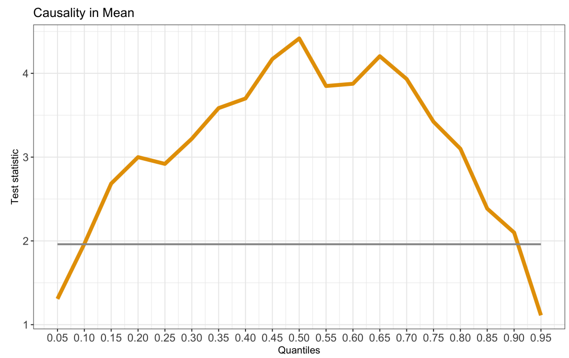


(d) Risk shock to Bitcoin

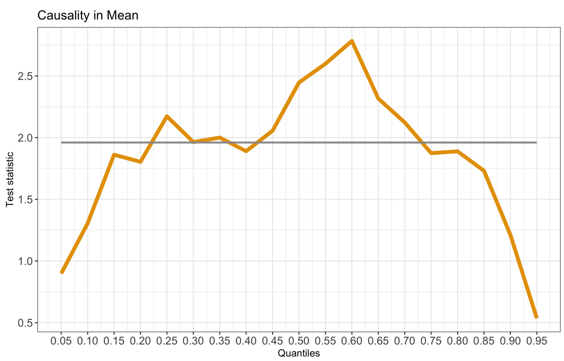
Figure 2: Causality-in-quantile test results of the oil futures change and shocks on the Bitcoin price return. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



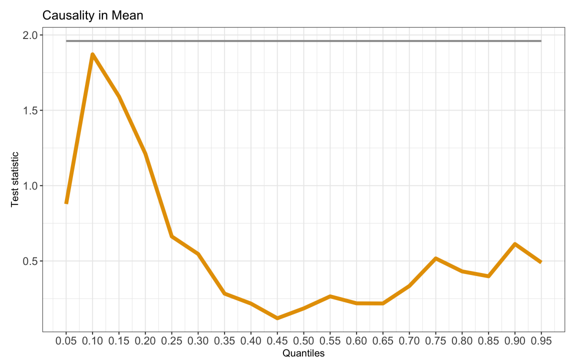
(a) Gold to oil futures



(b) Gold to supply shock

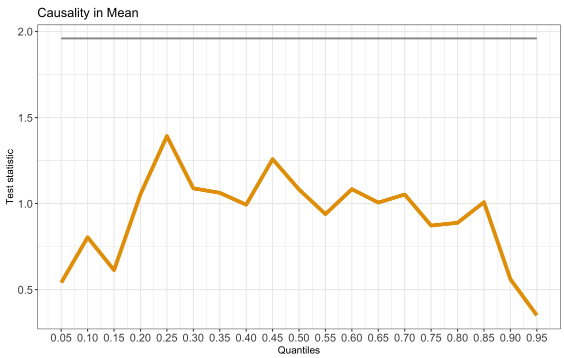


(c) Gold to demand shock

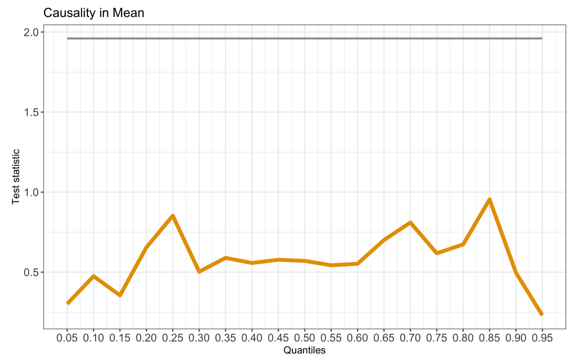


(d) Gold to risk shock

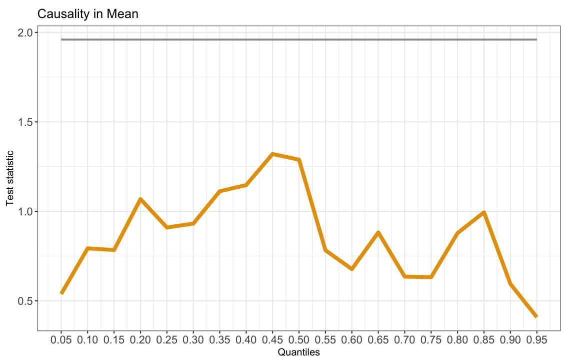
Figure 3: Causality-in-quantile test results of the gold price return on the oil futures change and shocks. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



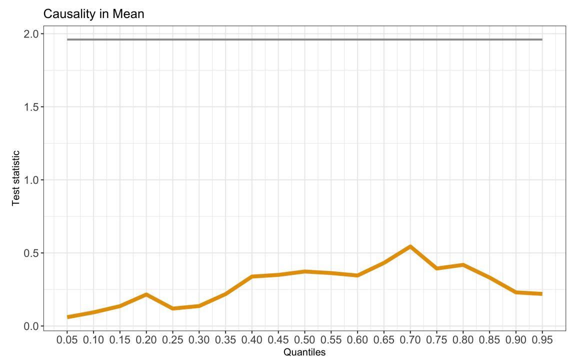
(a) Oil futures to gold



(b) Supply shock to gold

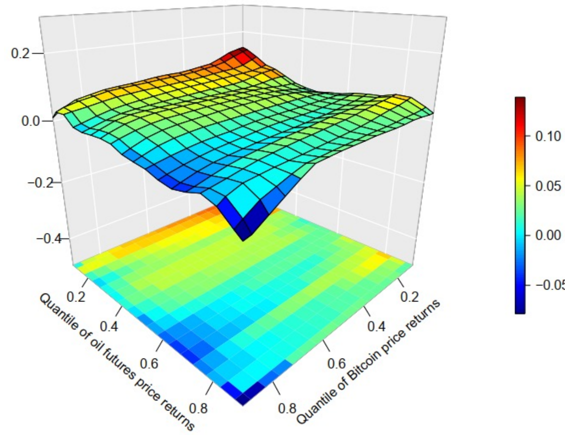


(c) Demand shock to gold

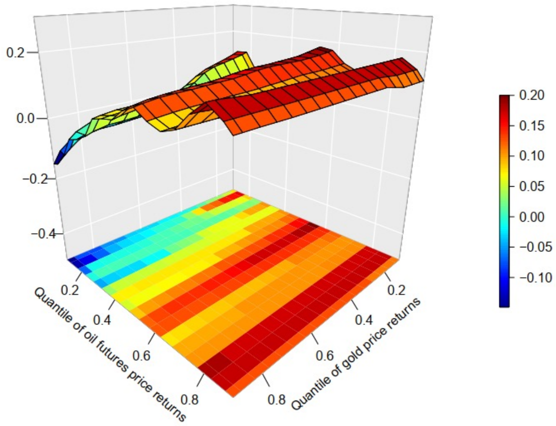


(d) Risk shock to gold

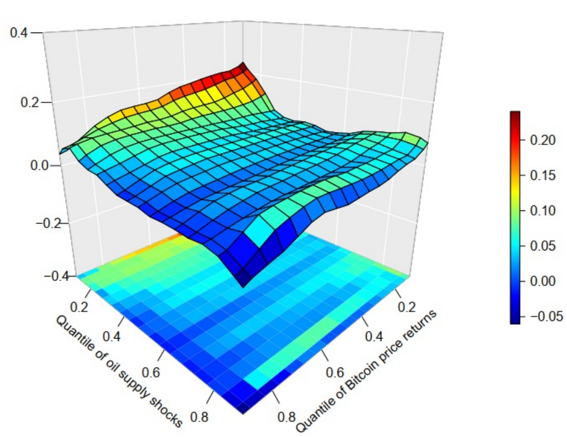
Figure 4: Causality-in-quantile test results of the oil futures change and shocks on the gold price return. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



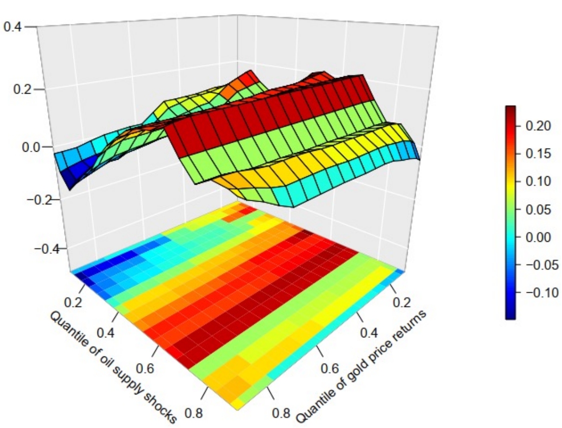
(a) Bitcoin to total oil change



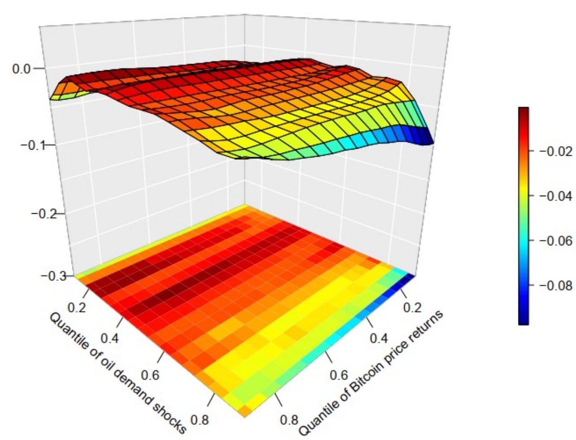
(b) Gold to total oil change



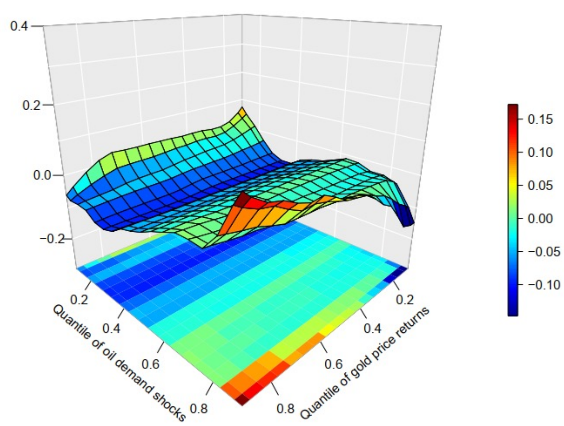
(c) Bitcoin to supply shock



(d) Gold to supply shock

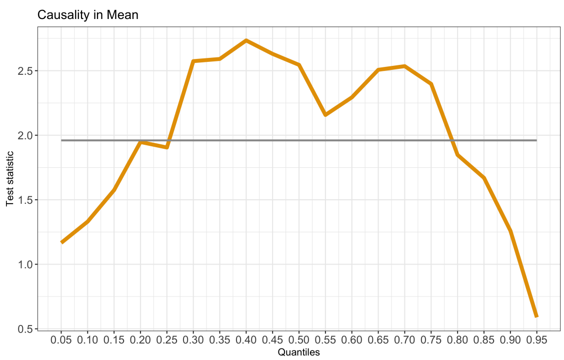


(e) Bitcoin to demand shock

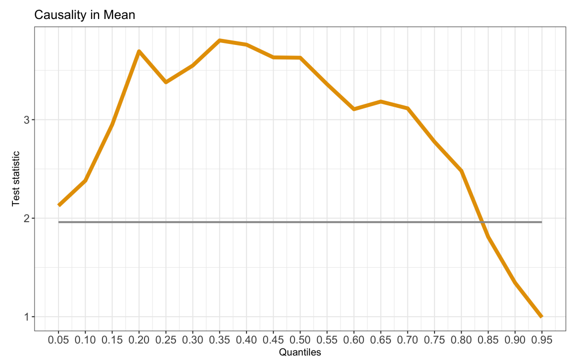


(f) Gold to demand shock

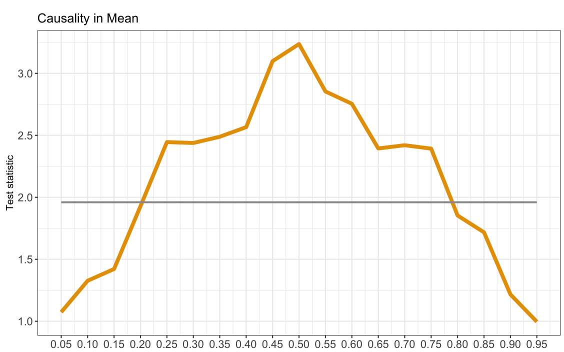
Figure 5: QQ estimates for impacts of Bitcoin/gold returns on oil price changes/shocks. Note: This graph depicts the estimates of $b_1(\tau,\gamma)$ in model (12), which is placed on the z-axis against the quantiles of the oil returns/shocks (τ) on the x-axis and the quantiles of Bitcoin/gold market returns (γ) on the y-axis. The colors in the color bar measure the magnitude of the Bitcoin/gold impact.



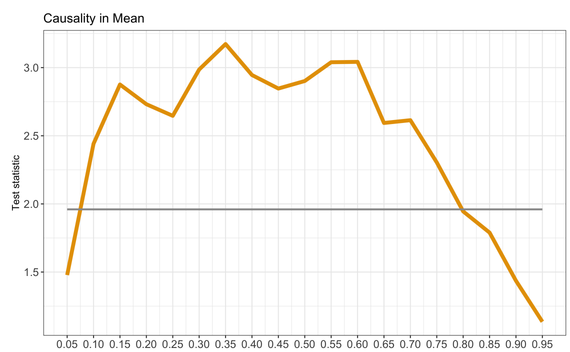
(a) Pre-COVID-19 bitcoin to oil futures



(b) Post-COVID-19 bitcoin to oil futures

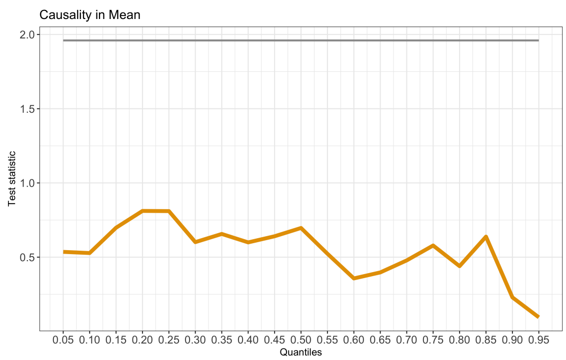


(c) Pre-COVID-19 gold to oil futures

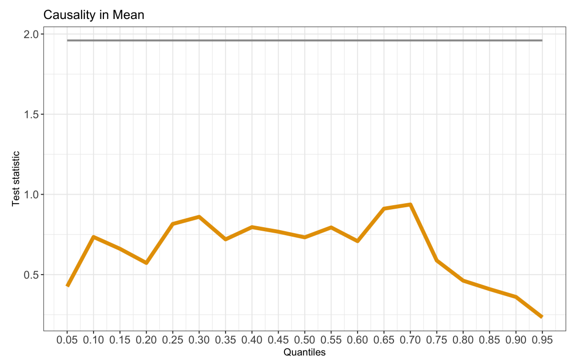


(d) Post-COVID-19 gold to oil futures

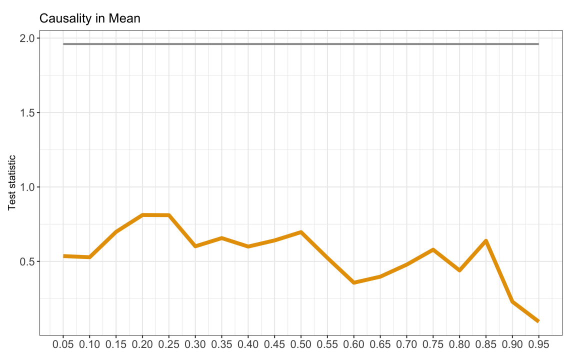
Figure 6: Causality-in-quantile test results of the Bitcoin and gold price return on the oil futures change pre- and post-COVID-19. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



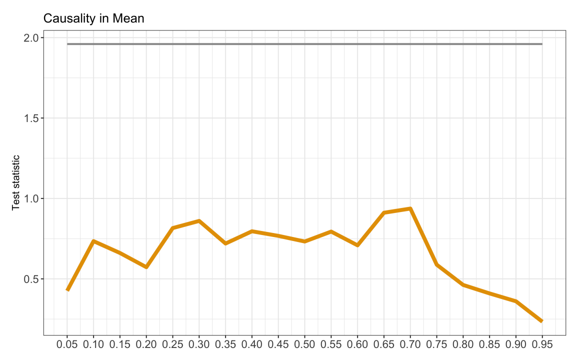
(a) Pre-COVID-19 oil futures to bitcoin



(b) Post-COVID-19 oil futures to bitcoin

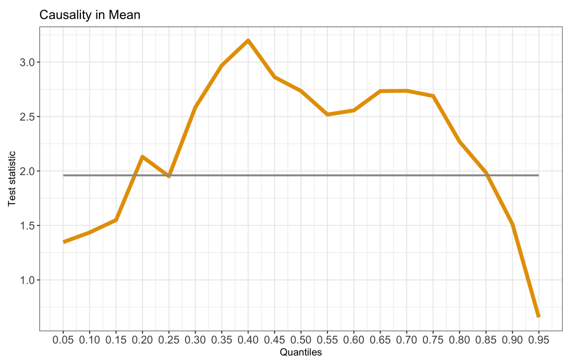


(c) Pre-COVID-19 oil futures to gold

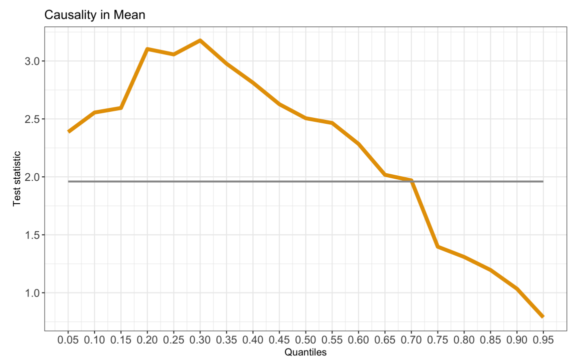


(d) Post-COVID-19 oil futures to gold

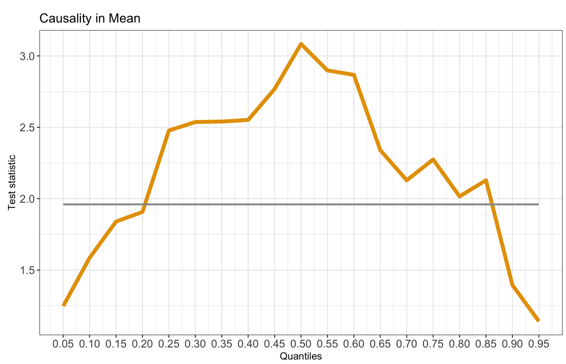
Figure 7: Causality-in-quantile test results of the oil futures change to Bitcoin and gold price return pre- and post-COVID-19. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



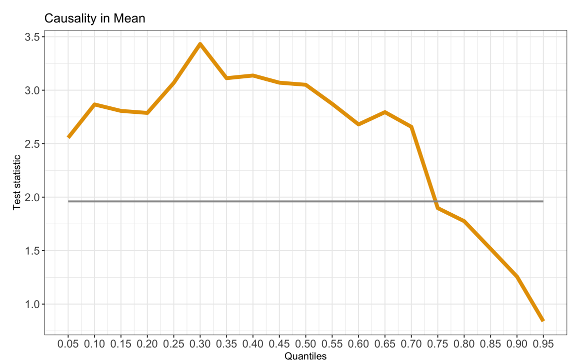
(a) Pre-UR conflict bitcoin to oil futures



(b) Post-UR conflict bitcoin to oil futures

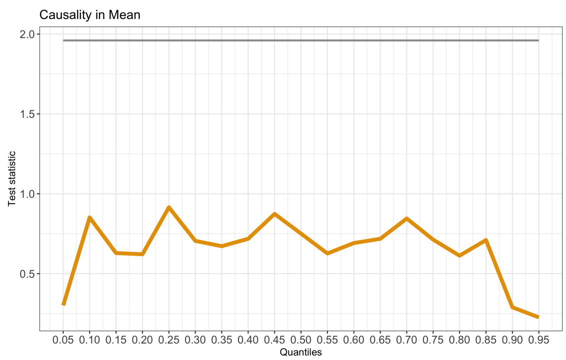


(c) Pre-RU conflict gold to oil futures

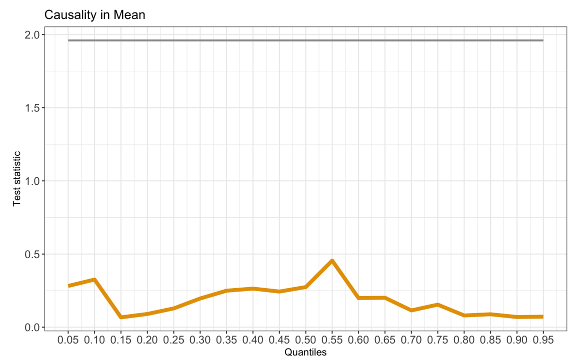


(d) Post-RU conflict gold to oil futures

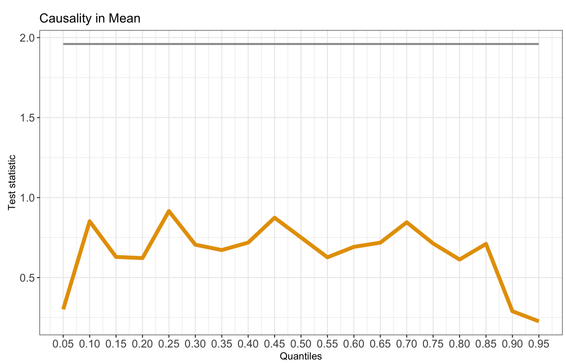
Figure 8: Causality-in-quantile test results of the Bitcoin and gold price return on the oil futures change pre- and post-RU conflict. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



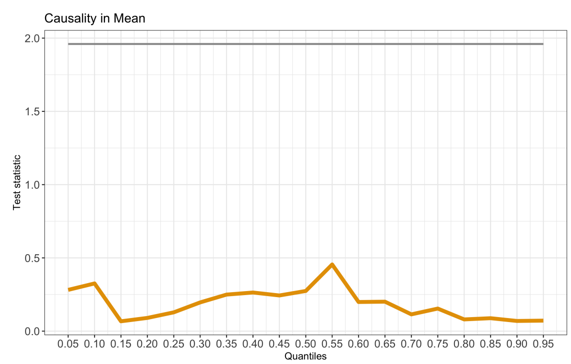
(a) Pre-UR conflict oil futures to bitcoin



(b) Post-UR conflict oil futures to bitcoin

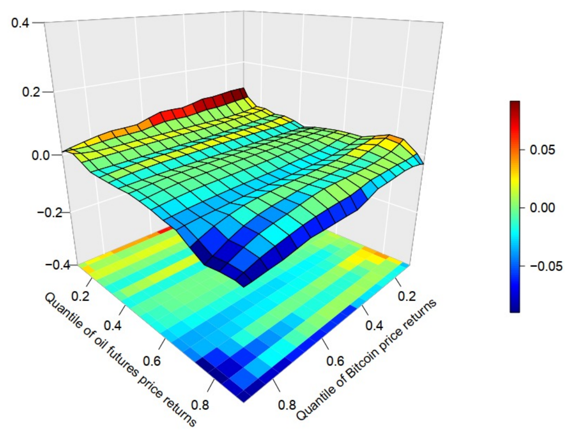


(c) Pre-UR conflict oil futures to gold

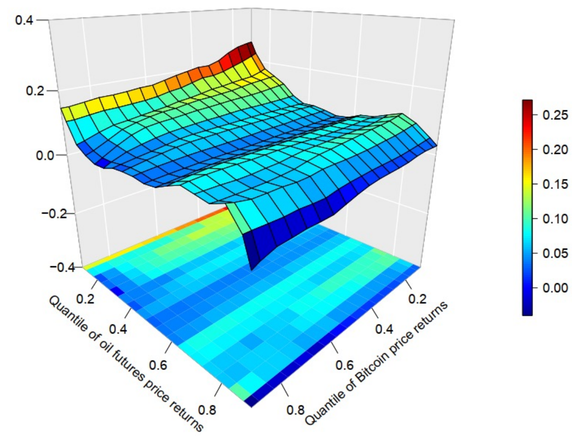


(d) Post-UR conflict oil futures to gold

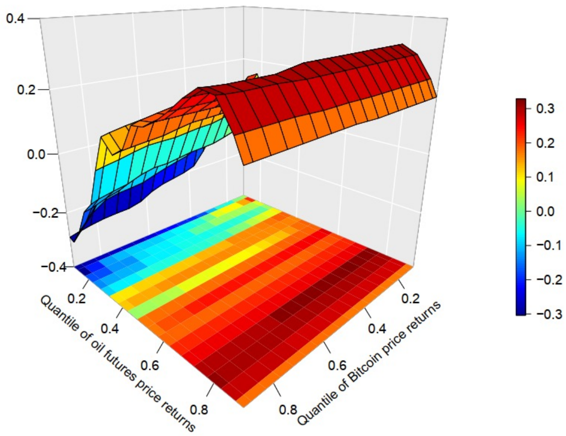
Figure 9: Causality-in-quantile test results of the oil futures change to Bitcoin and gold price return pre- and post-UR conflict. Note: (i) The horizontal gray solid line represents the 5% critical value. (ii) The vertical axis reports test statistics and the horizontal axis indicates quantiles(from q=0.05 to q=0.95).



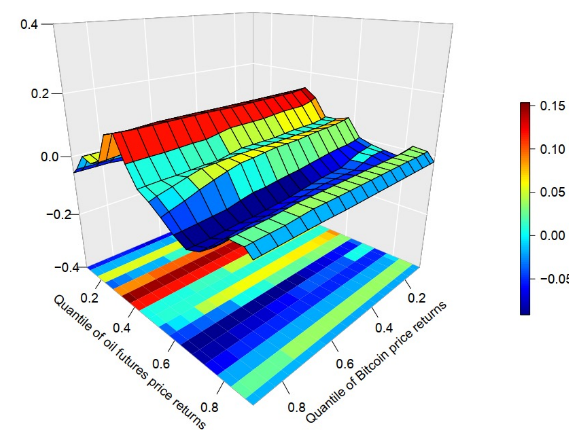
(a) Pre-COVID-19 Bitcoin to oil futures



(b) Post-COVID-19 Bitcoin to oil futures

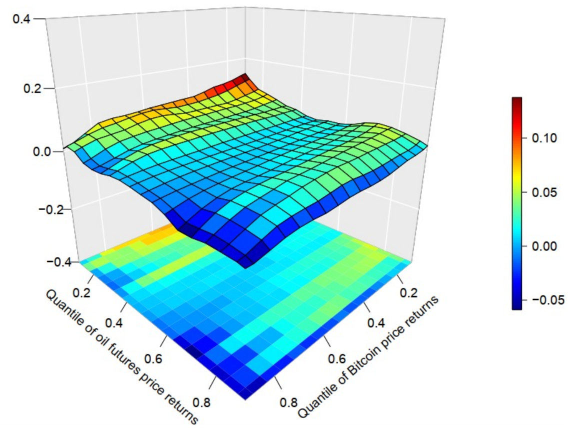


(c) Pre-COVID-19 gold to oil futures

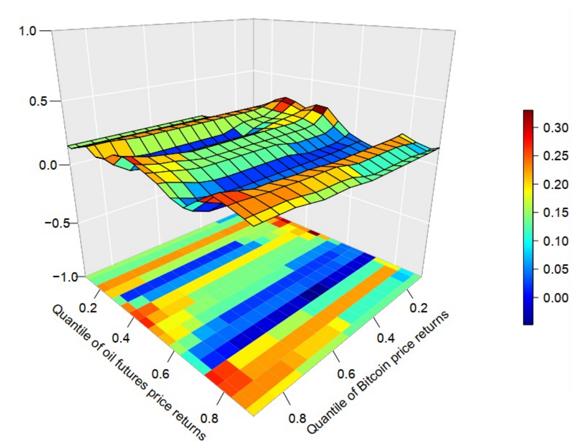


(d) Post-COVID-19 gold to oil futures

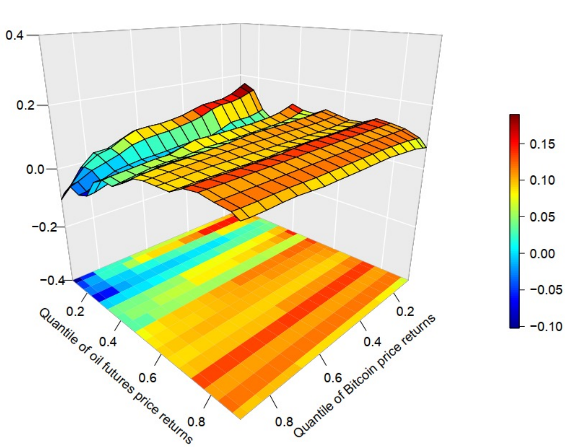
Figure 10: QQ estimates for impacts of Bitcoin/gold returns on oil price changes pre- and post-COVID-19. Note: This graph depicts the estimates of $b_1(\tau, \gamma)$ in model (12), which is placed on the z-axis against the quantiles of the oil returns (τ) on the x-axis and the quantiles of Bitcoin/gold market returns (γ) on the y-axis. The colors in the color bar measure the magnitude of the Bitcoin/gold impact.



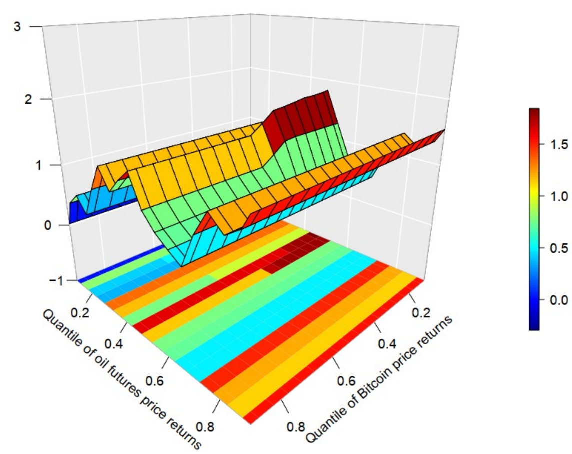
(a) Pre-RU conflict Bitcoin to oil futures



(b) Post-RU conflict Bitcoin to oil futures

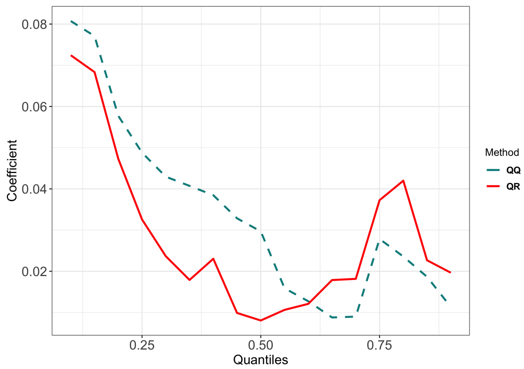


(c) Pre-RU conflict gold to oil futures

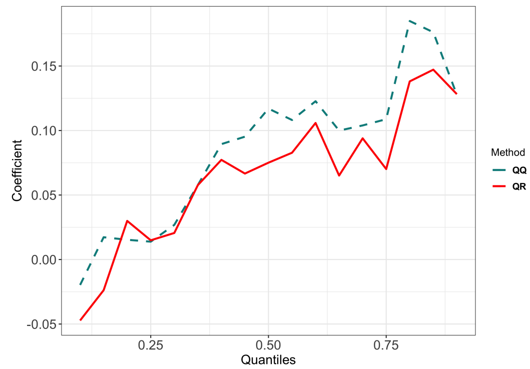


(d) Post-RU conflict gold to oil futures

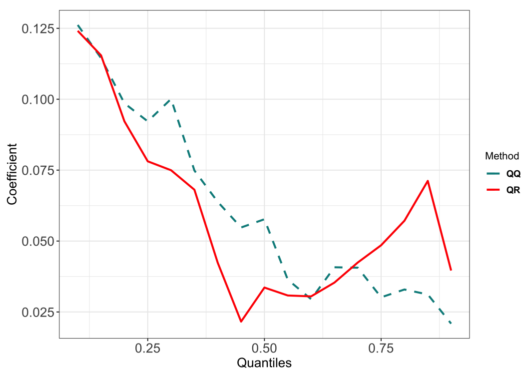
Figure 11: QQ estimates for impacts of Bitcoin/gold returns on oil price changes pre- and post-RU conflict. Note: This graph depicts the estimates of $b_1(\tau, \gamma)$ in model (12), which is placed on the z-axis against the quantiles of the oil returns (τ) on the x-axis and the quantiles of Bitcoin/gold market returns (γ) on the y-axis. The colors in the color bar measure the magnitude of the Bitcoin/gold impact.



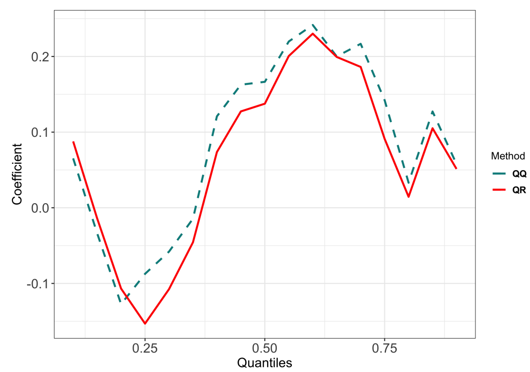
(a) Bitcoin to total oil change



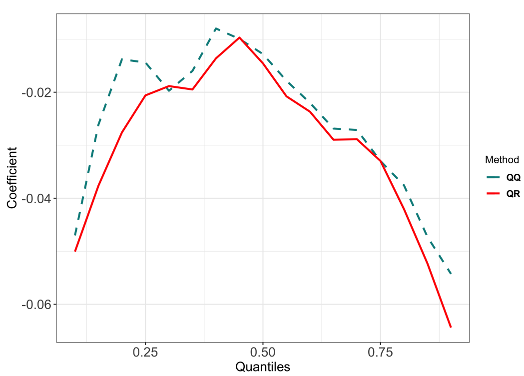
(b) Gold to total oil change



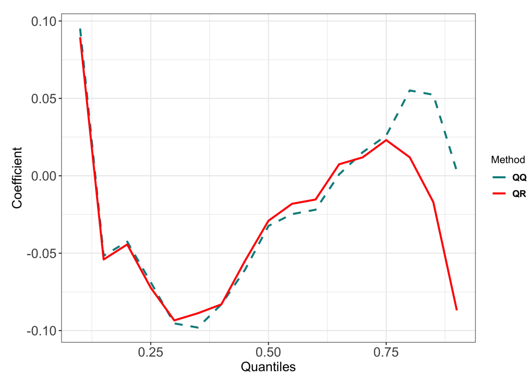
(c) Bitcoin to supply shock



(d) Gold to supply shock

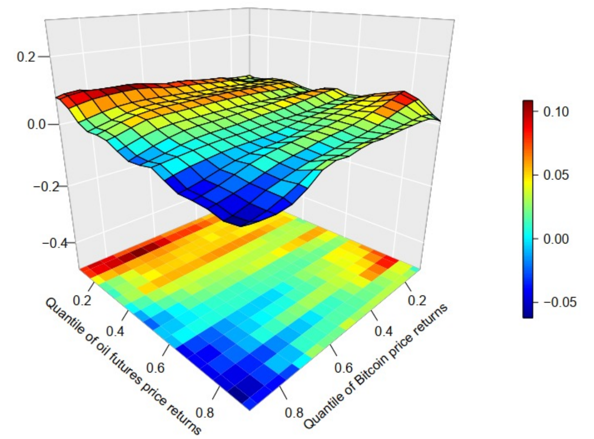


(e) Bitcoin to demand shock

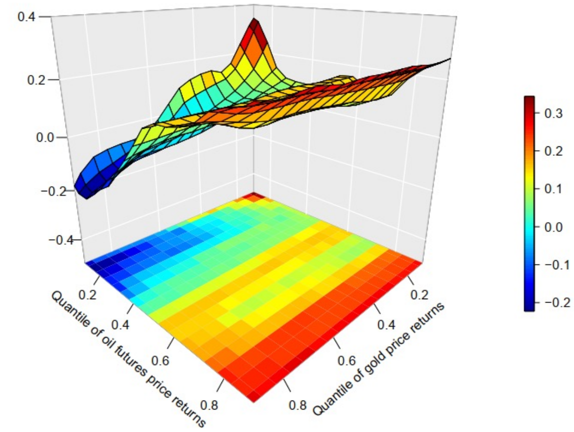


(f) Gold to demand shock

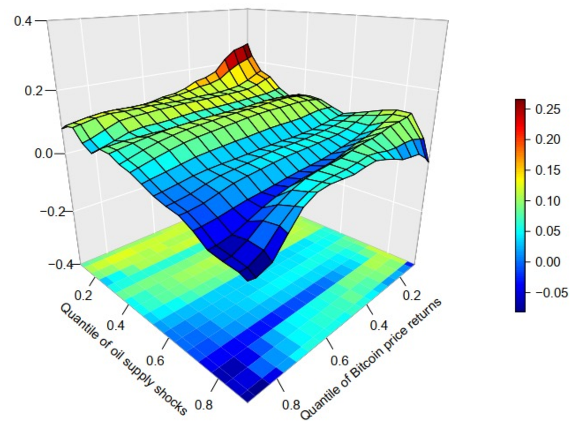
Figure 12: Comparisons of the results from the quantile regression(QR) and the QQ estimate for robustness check. Note: The green dashed line represents the parameter estimates of QR at different quantiles, the red solid line for each value is the average of the QQ estimates of different quantiles of Bitcoin and gold returns on oil price changes.



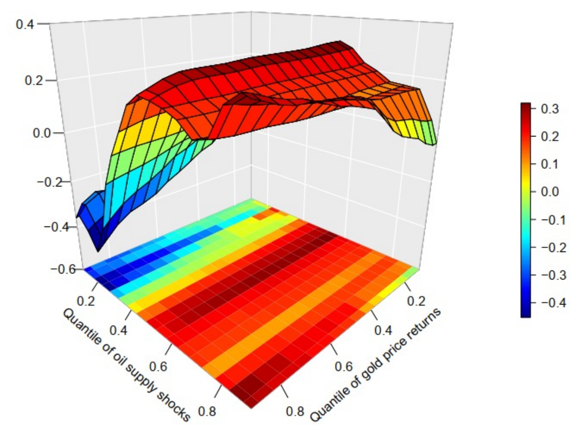
(a) Bitcoin to total oil change



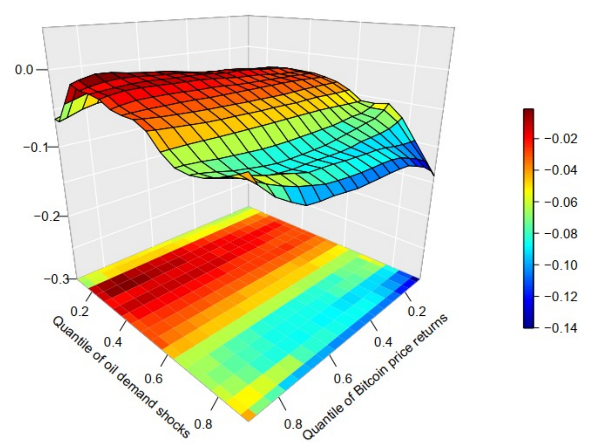
(b) Gold to total oil change



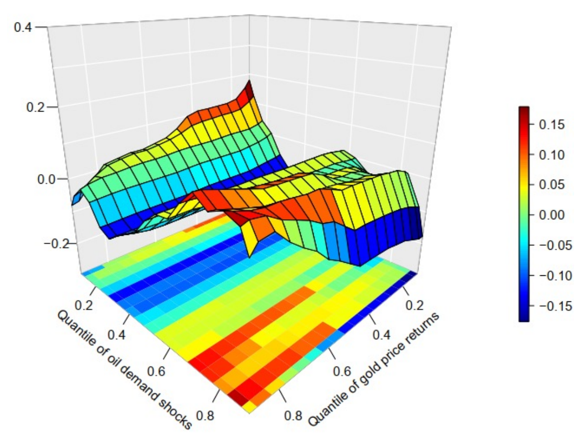
(c) Bitcoin to supply shock



(d) Gold to supply shock



(e) Bitcoin to demand shock



(f) Gold to demand shock

Figure 13: The robustness check: QQ estimates for impacts of Bitcoin/gold returns on oil price changes/shocks. Note: This graph depicts the estimates of $b_1(\tau, \gamma)$ in model (12), which is placed on the z-axis against the quantiles of the oil returns (τ) on the x-axis and the quantiles of Bitcoin/gold market returns (γ) on the y-axis. The colors in the color bar measure the magnitude of the Bitcoin/gold impact.