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Asymmetric spillover from Bitcoin to green and traditional assets: A comparison with gold

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ABSTRACT

This paper studies asymmetric spillovers from Bitcoin to green and traditional assets by using a full distributional framework established by a recently-developed Quantile-on-Quantile approach. The spillovers from gold to the same are further studied to compare the effectiveness of the underlying digital investment shelter of Bitcoin with its traditional counterpart of gold. Statistical evidence indicates that the cross-market spillover features evident asymmetry and non-linearity from three perspectives involving various quantiles of the joint distribution of dependent and independent variables, data in return and volatility, and before/after the COVID-19 pandemic. The investment sheltering role of Bitcoin is examined by its weakly positive, negligible, or even negative dependence with financial assets under different market conditions, while such the role is found to be relatively stronger for green assets compared to that for traditional assets. Moreover, the digital investment shelter is shown to be more effective than the traditional shelter given Bitcoin's weaker or even more negative dependence with both green and traditional financial assets than gold. Additional analyses confirm the robustness of our findings that should be of interest to various stakeholders.

1. Introduction

Bitcoin, as one of the mainstream cryptocurrencies given its simplicity, transparency and increasing popularity, has nowadays received widespread attention (Urquhart, 2016). Bitcoin was born based on cryptography to control its creation and management rather than relying on surveillance of any Sovereign authority. It is therefore known that Bitcoin could generally act as a safe haven for financial investments given its unique risk-return characteristics compared to traditional assets so that its dynamics should not be prone to fluctuations in Sovereign States (Kliber et al., 2019).[1] At the same time, since increasing market financialisation worldwide over time, the efficacy of the traditional safe haven asset, i.e., gold, has been questioned, calling for the usage of its digital alternative in terms of the investment shelter (Klein, 2017). Despite economic benefits, carbon-intensive cryptocurrencies notably Bitcoin would result in heavy carbon footprints due to massive energy consumption for mining and trading activities, leading to worldwide attention to the impact of cryptocurrency on environmental sustainability (see, e.g., Corbet et al., 2022; Corbet & Yarovaya, 2020; Duan & Urquhart, 2023; Huang et al., 2023).

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[1] Definitions of different types of investment shelters including safe haven, hedge, and diversifier have been detailed in the conceptual discussion from Baur and Lucey (2010). In specific, an asset is defined as a safe haven (or hedge) when it is uncorrelated or even negatively correlated with another asset or portfolio in the period of depression (or on average). A diversifier is an asset having a positive (but not perfect) correlation with another asset or portfolio on average.

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To combat global warming, investments in renewable and green energy (named as green assets in the paper) have boomed over the recent decade (Ren & Lucey, 2022). Due to a short period of development, although emerging, green assets still feature a relatively limited market depth compared to traditional assets, leading to a higher risk of investing in green assets. It therefore demonstrates a necessity to explore an effective strategy for the promising but riskier green assets in diversification and risk mitigation (Pham, 2016). By far, although the linkage of Bitcoin with the financial system has raised heated discussion, no consensus has been reached. On the one hand, cryptocurrencies notably including Bitcoin are known to feature an investment sheltering property for financial assets so that the linkage could be weak or even negative (Bouri et al., 2020; Feng et al., 2023; Huang et al., 2021). Moreover, given the contradiction between the carbon-friendly green investment and the carbon-intensive Bitcoin, the linkage between the two could be rather weak (Huang et al., 2023). On the other hand, given that cryptocurrency trading has been increasingly popular over time, a rising adoption of cryptocurrency-related products in financial investments could strengthen such the linkage (Duan et al., 2023; Elsayed et al., 2022). While the linkage between Bitcoin and traditional assets has witnessed a wide discussion, little attention has been raised on whether and how Bitcoin can act as a shelter for green assets. Moreover, there is also a lack of research to compare the effectiveness of the potential sheltering role of Bitcoin for traditional and green assets.

Against the above backdrop, this paper fills the gap by comparing the linkage of Bitcoin with traditional and green assets within a full distributional framework where the cross-market linkage at various quantiles of both the dependent and independent variables can be examined. Another comparison regarding the effectiveness of Bitcoin and gold to shelter against adverse fluctuations of (traditional and green) financial assets is also examined. Specifically, the potential asymmetry and non-linearity of the market nexus of Bitcoin with green and traditional assets over the full data distribution is analyzed by using a recently-developed quantile-on-quantile (QQ) method developed by Sim and Zhou (2015).[2] The cross-market nexus is constructed from the two perspectives of data in return and volatility, respectively.[3] A comparison between Bitcoin and gold regarding their sheltering role is further made with its potential dynamics before and after the COVID-19 pandemic being also investigated. A series of additional analyses have been further conducted to examine robustness of our main findings.

Our research contributes to the extant literature on following aspects. First, unlike conventional mean-based estimation or traditional quantile regression, our employed QQ method establishes a full distributional environment, through which the potential asymmetry of the cross-market information spillover over the joint distribution of both dependent and independent variables can be captured. Second, our full-distributional setting built by the QQ method enriches interpretation on the sheltering role of Bitcoin/gold against financial assets. Through this, we extend the literature by investigating whether and how different traditional and green assets respond to the dynamics of Bitcoin/gold assets. The research outcome is expected to offer a comprehensive illustration regarding the cross-market linkages of potential sheltering assets with both traditional and green assets over the joint data distribution. Moreover, rather than only a static analysis, dynamics of the market linkages in the face of the pandemic shock is further captured through the sample stratification.

Overall, through a full and joint distributional analysis by the QQ estimation, several important findings emerge and are summarized on the following aspects. First, our results confirm the asymmetric correlation of Bitcoin/gold with financial assets. Such the asymmetry is captured from three perspectives, i.e., different quantiles of the data distribution, before/after the pandemic, and data in return and volatility, respectively. Second, the dynamics of the correlation varies depending on the potential investment shelter (i.e., Bitcoin/gold) and target financial assets (i.e., green/traditional) across different quantiles over the data distribution. Third, While Bitcoin can act as an investment shelter for different financial assets, its effectiveness for green assets is found to be stronger than traditional counterparts. Following the definition discussion by Baur and Lucey (2010), Bitcoin's sheltering role could be as either a diversifier, a hedge, and safe haven in different market conditions. Fourth, the investment sheltering role of Bitcoin tends to be stronger than that of gold given its relatively weaker or even more negative dependence with different financial assets, showing good performance of Bitcoin in regard to diversification and risk mitigation. Our results possess insightful implications for effective diversification and risk mitigation of financial investment portfolios under various market conditions that should be of interest to various stakeholders.

The remainder of the paper proceeds as follows. Section 2 presents a succinct review of key literature. Section 3 describes employed estimation techniques and data. Section 4 discusses our empirical results and corresponding theoretical explanations. Section 5 concludes with a discussion of results in the context of policy.

2. Literature review

Our paper is closely linked to the extant literature on the market dependence of Bitcoin and gold with traditional and green financial assets, with a particular focus on the role of Bitcoin and gold as a hedge or safe haven under steady and volatile market situations. Regarding the price fluctuations of Bitcoin and traditional financial assets, existing literature has revealed the potential

[2] Noteworthy, the cross-market nexus is built through a lead–lag structure in our research. This is in response to the potential bidirectionality of the contemporaneous relationship between Bitcoin and financial assets, and a failure to consider this would result in the endogeneity issue of simultaneity. Following the extant literature (see, e.g., Coglianese et al., 2017; Duan et al., 2021b; Lin & Benjamin, 2019), our QQ model specification is determined based on the argument that past Bitcoin price dynamics are predetermined against current financial price dynamics. Accordingly, our research sets the time-lagged term of Bitcoin price return and the contemporaneous term of financial asset price return as the independent variable and the dependent variable, respectively. Similar research design that applies a lead–lag structure to study the safe haven role of Bitcoin can be also found in existing literature (see, e.g., Huang et al., 2021).

[3] Following recent works in related fields (see, e.g., Urquhart, 2018), the series of volatility of the target asset/commodity is constructed through the manner of realized volatility, i.e., the squared daily return, in the light of the method introduced by Andersen et al. (2003).

role of Bitcoin as a diversifier, a hedge, and/or a safe haven relative to financial assets, and the size and type of the capabilities are closely related to market stability (Bouri et al., 2020; Conlon et al., 2020; Duan et al., 2021a; Dutta et al., 2020). Gil-Alana et al. (2020) use fractional cointegration techniques to conclude that the cryptocurrencies are decoupled from the mainstream financial and economic assets, which implies the role of cryptocurrencies as a diversifier. Hsu et al. (2021) apply a diagonal BEKK model to capture the asymmetric co-volatility spillover effects between major cryptocurrencies and traditional currencies which means the negative return shocks have larger impacts on co-volatility than positive return shocks. Charfeddine et al. (2020) also support the statement that cryptocurrencies can be suitable for financial diversification, and they find evidence that the relationship between cryptocurrencies and conventional assets is sensitive to external economic and financial shocks. In addition, some of the literature has studied the linkages between cryptocurrencies and commodity markets. Maghyereh and Abdoh (2020) find that the dependence between Bitcoin and commodity notably crude oil and silver decreases the most around medium data quantiles in the short term.

As for the market linkages between Bitcoin and green financial assets, although the existing literature has some discussion on the shelter function of green bonds for Bitcoin, no consensus has been made by far (Kamal & Hassan, 2022; Naeem & Karim, 2021; Ren & Lucey, 2022). Le et al. (2021) examine the time and frequency domain volatility connectedness among cryptocurrencies, green bonds, and Fintech, which concludes Bitcoin acts as a net contributor of volatility shocks whereas green bonds are net receivers. Kamal and Hassan (2022) analyze the impact of the cryptocurrency environment attention index (ICEA) on clean energy stocks and green bonds. Their finding suggests that clean energy stocks and green bonds have diversification potential against ICEA due to weak and insignificant relationships and low volatility spillovers based on OLS and quantile regression results. Naeem and Karim (2021) utilize the time-varying optimal copula (TVOC) approach to showcase the asymmetric and time-varying dependence structures between Bitcoin and green financial assets. The hedging effect of green assets on Bitcoin is also confirmed in their research. Corbet et al. (2022) provide new evidence to investigate Bitcoin-energy markets interrelationships. They illustrate how Bitcoin's price volatility and the underlying dynamics of cryptocurrency mining characteristics affect underlying energy markets and utilities companies. However, Ren and Lucey (2022) point out that clean energy is not a direct hedge for both "clean" and "dirty" cryptocurrencies, but it serves as a weak safe haven for both in the extreme bearish market. Therefore, the market dependence between Bitcoin and green financial assets needs to be further analyzed.

Except for Bitcoin, the role of gold as a safe haven or hedge has also been largely discussed. Regarding the price interactions between the gold market and conventional financial markets, gold has traditionally played the role of hedging in normal times and as a safe haven in times of market turmoil (Balcilar et al., 2020; Shahzad et al., 2019; Yousaf et al., 2022). By resorting to the DCC-GARCH model, Dutta et al. (2020) find that gold serves as a safe haven for both WTI and Brent crude oil markets amid the COVID-19 outbreak. Hung and Vo (2021) examine the weak market connectedness between gold and $S\&P$ 500 by utilizing wavelet coherence analysis, which suggests that the gold asset might play a prominent role as a safe haven during extreme stock and crude oil market movements. In addition, some literature compares the hedging and safe-haven performance of Bitcoin and gold (Bouri et al., 2020; Das et al., 2020; Naeem et al., 2020; Shahzad et al., 2020). For instance, Das et al. (2020) suggest that Bitcoin outperforms gold and commodity in hedging crude oil implied volatility (OVX), while gold acts as a better safe haven against OVX as compared to Bitcoin. Similarly, Shahzad et al. (2020) point out that gold and Bitcoin have distinct safe haven and hedging characteristics, which means gold is an undisputable safe haven and hedge for several G7 stock indices, whereas Bitcoin only operates as such in Canada.

Although there is a scarcity of empirical evidence connecting gold to the green financial markets, some literature investigates the capabilities of hedging and the safe haven of gold for green financial assets (Dutta et al., 2021; Huynh et al., 2020; Yan et al., 2022). Yan et al. (2022) apply a quantile autoregressive lagged approach to prove that gold can be viewed as an effective hedge for green bonds since green bonds are negatively linked to world gold prices. The role of gold as a hedge and safe haven is also emphasized by Huynh et al. (2020). They investigate tail dependence and volatility interconnectivity along with a range of conventional and new asset categories including green bonds, AI stocks, gold, and Bitcoin. However, no consensus has been reached on the effectiveness of the role of gold as a hedge and safe haven based on the existing literature. For example, Elie et al. (2019) reveal that both crude oil and gold only act as a weak safe haven for clean energy indices by considering single and mixture copula approaches. Therefore, there is still a research gap on the market interdependence between gold and green financial assets.

3. Methodology and data

3.1. Methodology: The quantile-on-quantile method

This section discusses the quantile-on-quantile (QQ) method developed by Sim and Zhou (2015) for investigation of the asymmetric nexus of Bitcoin and gold with green and traditional assets. Unlike the traditional quantile regression, the QQ method applies the non-parametric estimation to analyze how various quantiles of the independent variables affect the conditional quantiles of the dependent variable. Strengths of our employed QQ method are discussed as follows through the statistical perspective.

First, in contrast to conventional mean-based methods, the QQ method offers a feasible way to account for heterogeneity in data distributions of both explanatory and dependent variables. Through this, QQ method plots a comprehensive picture of the pair-wise relationship of target variables under different market conditions in a full-distributional manner. Second, the QQ method helps relax the conventionally imposed linear setting, and captures the presence of non-linearity of the relationship between explanatory and dependent variables. Third, the lead–lag data structure applied in our QQ model setting alleviates the endogeneity problem of simultaneity, contributing to accurate estimation results. Fourth, via a *cross-validation method*, we improve the original version of the QQ method to select a more suitable bandwidth, through which a better trade-off between the bias and the variance of the estimation is made. Thus, it is clear that the QQ method can better unravel the potentially asymmetric nexus between Bitcoin/gold and financial assets against both OLS and traditional quantile regressions.

We begin introducing the QQ method by first considering the following nonparametric quantile regression equation for the θ-quantile of the asset (either traditional or green) price return (A_t) as a function of Bitcoin price return (B_{t-1}) as:

$$A_t = \beta^\theta(B_{t-1}) + \alpha^\theta(A_{t-1}) + \epsilon_t^\theta \tag{3.1}$$

where A_{t-1} represents the asset price return at time $t-1$, B_{t-1} represents the Bitcoin price return at time $t-1$, the residual term ϵ_t^θ has a zero θ-quantile. β^θ indicates the impact of the θ-quantile of the first-order lag of the Bitcoin return (B_{t-1}) on the asset return (A_t), and α^θ indicates the impact of the θ-quantile of the first-order lag of the asset return (A_{t-1}) on the asset return (A_t). Due to the lack of prior information on the relationship, $\beta^\theta(\cdot)$ is assumed to be an unknown function.

To examine the impact of the τ-quantile of the Bitcoin price shocks on θ-quantile of the asset price return, we expand the unknown function $\beta^\theta(\cdot)$ by taking a first order Taylor expansion around B^τ:

$$\beta^\theta(B_{t-1}) \approx \beta^\theta(B^\tau) + \dot{\beta}^\theta(B^\tau)(B_{t-1} - B^\tau) \equiv b_0(\theta,\tau) + b_1'(\theta,\tau)(B_{t-1} - B^\tau). \tag{3.2}$$

By substituting Eq. (3.2) into Eq. (3.1), we can obtain

$$A_t = \beta^\theta(B^\tau) + \dot{\beta}^\theta(B^\tau)(B_{t-1} - B^\tau) + \alpha^\theta A_{t-1} + \epsilon_t^\theta. \tag{3.3}$$

Then, we solve Eq. (3.3) by considering

$$\begin{pmatrix} \hat{b}_0(\theta,\tau) \\ \hat{b}_1(\theta,\tau) \end{pmatrix} = \arg\min_{b_0,b_1} \sum_{t=1}^{T} \rho_\theta \left[A_t - b_0 - b_1\left(B_{t-1} - B^\tau\right)\right] K\left(\frac{F\left(B_{t-1}\right) - \tau}{h}\right), \tag{3.4}$$

where $\rho_\theta(y) = y(\theta - I_{\{y<0\}})$ and I_w is the indicator function of set w. K is a Gaussian kernel function on $\mathbb{R}$, and $h > 0$ is the bandwidth. The empirical distribution function is defined as $F\left(B_{t-1}\right) = \frac{1}{T}\sum_{k=1}^{T} I\left(B_k < B_{t-1}\right)$.

The bandwidth selection is important for the non-parametric estimation due to the fact that the bandwidth decides both the variance and bias in the estimation. Therefore, a sensible trade-off between the bias and the variance entails an appropriate choice of the bandwidth. Extant related literature (see, for example, Sim & Zhou, 2015) uses a constant bandwidth, i.e., $h = 0.05$, which may not be suitable for different real data and cause biased estimation results. As a further extension, we follow Duan et al. (2021b) by using a cross-validation method (Li & Racine, 2004; Stone, 1984) to select the optimal bandwidth. The leave-one-out cross-validation estimator of Eq. (3.3) is

$$M(h) = \sum_{k=1}^{T} \rho_\theta\left(A_k - \hat{b}_{0,-k} - \hat{b}_{1,-k} B_{k-1}\right), \tag{3.5}$$

where $\hat{b}_{0,-k}$ and $\hat{b}_{1,-k}$ are the local linear estimators obtained in Eq. (3.4) after removing the initial kth observation. The optimal bandwidth parameter is then formulated as:

$$h_{CV} = \arg\min_h M(h). \tag{3.6}$$

3.2. Data

Our research database includes daily price series of Bitcoin, gold, four green financial assets (i.e., SWI, ESGLI, GBI and GCEI) and five traditional financial assets (i.e., S&P ASX 200, S&P TSX, STOXX 600, FTSE 100 and S&P 500) spanning from 1 May 2013

Table 1
Descriptive statistics.

0	*BTC*	*GOLD*	*GREEN*	*STOCK*
Minimum	−46.473	−6.024	−11.318	−13.277
Maximum	35.745	5.133	8.488	10.561
25th Quartile	−1.372	−0.471	−0.402	−0.424
75th Quartile	1.882	0.495	0.547	0.545
Mean	0.177	0.013	0.042	0.011
Stdev	4.215	0.947	1.043	1.048
Skewness	−0.517	−0.178	−1.073	−1.738
Kurtosis	13.901	6.975	17.936	31.063
JB test	16 242.115***	1483.281***	21 278.779***	71 432.330***
ADF test	−58.158***	−48.282***	−14.626***	−15.632***

Note: (i) This table summarizes descriptive statistics of the price return of Bitcoin, gold futures, green and traditional financial assets portfolio. (ii) The sample period is from 1 May 2013 to 25 March 2022. (iii) The Jarque–Bera (JB) statistics test for the null hypothesis of normality of target series. The Augmented Dickey–Fuller (ADF) test reports unit root test results with the null hypothesis of non-stationarity. (iv) * denotes the 10% significance level; ** denotes the 5% significance level; *** denotes the 1% significance level.

to 25 March 2022. Specifically, Bitcoin prices (BTC) are from CoinMarketCap (www.coinmarketcap.com), gold prices ($GOLD$) are from the London P.M. gold fixing price from LBMA (www.lbma.org.uk). The daily closing price series of the four green assets are from S&P Dow Jones Indices database (www.spglobal.com), and prices of traditional assets are represented by the stock price index from Investing (www.investing.com). Using the above individual series of green assets and traditional assets, we accordingly create two value-weighted portfolio indices to proxy the market dynamics of the green assets ($GREEN$) and traditional assets ($STOCK$), respectively. All the price series are converted to U.S. dollars to eliminate the effect of local currencies.

Table 1 summaries the statistics for all the incorporated series transformed in the return format. The Jarque–Bera (JB) test shows that the null hypothesis of normality for all series are rejected at the 1% level. All the transformed series are shown to reject the null of the ADF test speaking in favor of stationarity.

4. Empirical results

4.1. Main results

In this section, we provide an empirical investigation regarding the investment sheltering property of Bitcoin and further analyze the potential difference of its sheltering property against green and traditional assets in a full and joint distributional environment. Specifically, when playing as a potential investment shelter, how different would the role of Bitcoin be to contribute to the risk hedging/mitigation for green and traditional assets? To answer this question, we examine the asymmetric and nonlinear correlation of Bitcoin with green and traditional assets over the joint data distribution of dependent and independent variables realized by the Quantile-on-Quantile (QQ) approach. Such the cross-market correlation is examined on both aspects of data in price return and volatility. Through this, asymmetry of the correlation of Bitcoin with green and traditional assets across all market conditions in bull, normal, and bear can be drawn in the 3-D picture. In addition, the sheltering role of Bitcoin is further compared with that of gold to examine the possible difference of the performance of the traditional investment shelter (i.e., gold) with its digital counterpart (i.e., Bitcoin).

Overall, the QQ estimation regarding the dependence of Bitcoin with green and traditional assets through both channels of data in price return and volatility over the whole data distribution are summarized in Figs. 1–4. Several important findings emerge and are summarized in the following aspects. In terms of the information spillover from Bitcoin to green and traditional assets, it is analyzed through the channel of price return and volatility shown in Figs. 1 and 2, respectively. Specifically, as for the channel of price return as drawn in Fig. 1, the dependence of Bitcoin with green assets is found to be overall weakly positive over the distribution and even negative at extremely lower quantiles of green markets. At the same time, its dependence with traditional assets tends to be overall relatively greater but also depicts a negative degree when traditional assets are in lower quantiles. That is, the correlation of Bitcoin with both green and traditional assets demonstrates a decreasing trend with decreases in quantiles of the price return of both two assets. In particular, the coefficient indicator (β^{θ}) is both negative for green and traditional assets at their low quantiles (less than 0.2). Such the coefficient is −0.03 in Fig. 1(a) and −0.1 in Fig. 1(b), indicating the negative correlation of Bitcoin with the former two asset types as seen in the dark blue area in Fig. 1. Overall, the above results show that the price return of Bitcoin has a weak correlation with both green and traditional assets, while its correlation with green assets is relatively lower than that with traditional assets. The safe haven property of Bitcoin for green and traditional assets is further examined by the negative degree of the correlation when the market of the latter two is in depression.

As for the channel of price volatility as drawn in Fig. 2, Bitcoin has an overall negative or weakly positive correlation with both green and traditional assets across different quantiles, while such the correlation pattern differs relying on different financial asset types. In specific, the dependence of Bitcoin with green assets experiences a hump-shaped dynamics across the data distribution. It first has an increasing trend from very low quantiles to higher ones of green assets until approaching to its 80% quantile after which the dependence then experiences a plunge. In contrast, the dependence of Bitcoin with traditional assets performs a relatively more flat pattern that its dependence degree is negative at extreme low quantiles of green assets and then turns to be constantly positive after that. These results indicate the sheltering role of Bitcoin for both green and traditional assets as either diversifier or hedge as defined by Baur and Lucey (2010) but the role tends to differ over financial asset types and market conditions. In particular, Bitcoin could even act as a safe haven for traditional assets given their negative dependence especially when the traditional asset market is in depression (as represented by its lower quantiles).

To sump up, similar to the channel of price return, the spillover from Bitcoin to green assets is also found to be relatively weaker compared to that to traditional assets through the channel of volatility, depicting better performance of Bitcoin for green assets in terms of diversification and risk mitigation. This speaks in favor of our expectation that given that Bitcoin features carbon-intensive footprints and green assets represent financial investment for carbon-friendly projects, such the contradiction results in a weak or even negative correlation between Bitcoin and green assets. At the same time, our results also generally confirm the investment sheltering property of Bitcoin for traditional assets over the data distribution. The results are in line with the existing literature (see, e.g., Huang et al., 2021, 2023; Naeem & Karim, 2021). For example, Naeem and Karim (2021) find that Bitcoin acts as an effective hedge for green assets, especially clean energy during the financial turmoil, while the hedging effectiveness differs across different asset types. Huang et al. (2021) document that Bitcoin offers different diversification benefits and/or risk reductions for stock and bond assets, and they also find that such the sheltering role of Bitcoin tends to vary across economies/regions and before/after the outbreak of the COVID-19 pandemic.

To further compare the investment sheltering role of Bitcoin with the traditionally recognized shelter, i.e., gold, the dependence between gold and financial assets is further examined from both channels of price return and volatility as shown in Figs. 3 and 4,

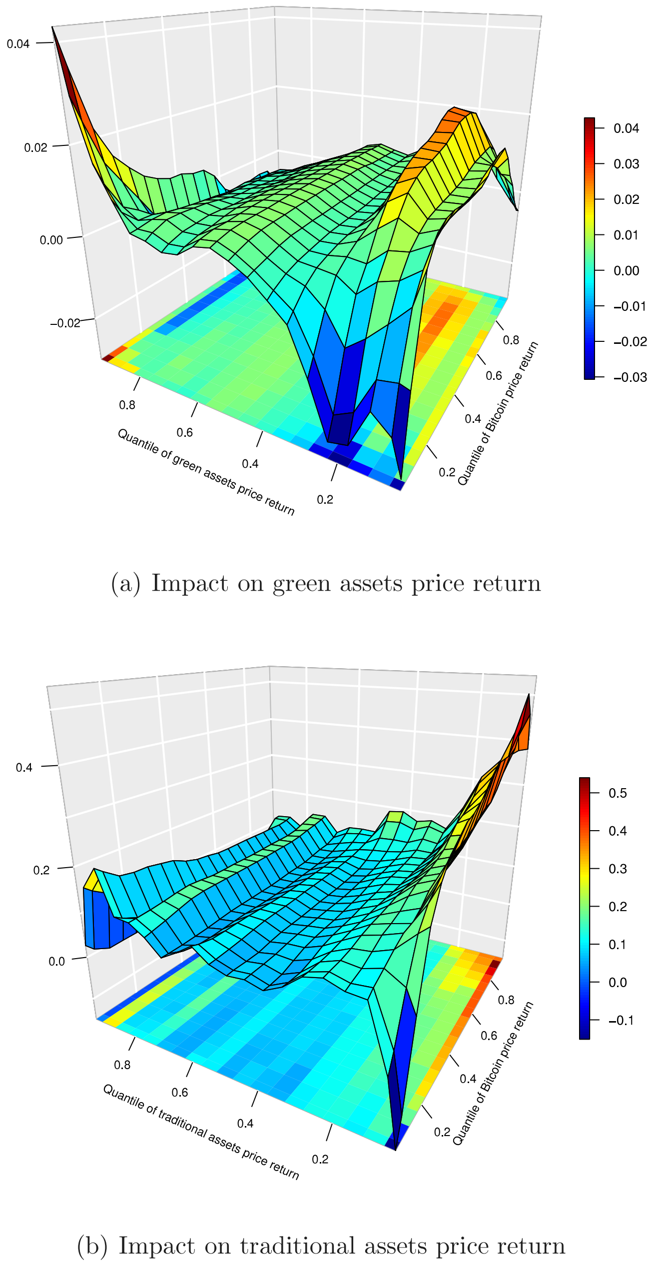
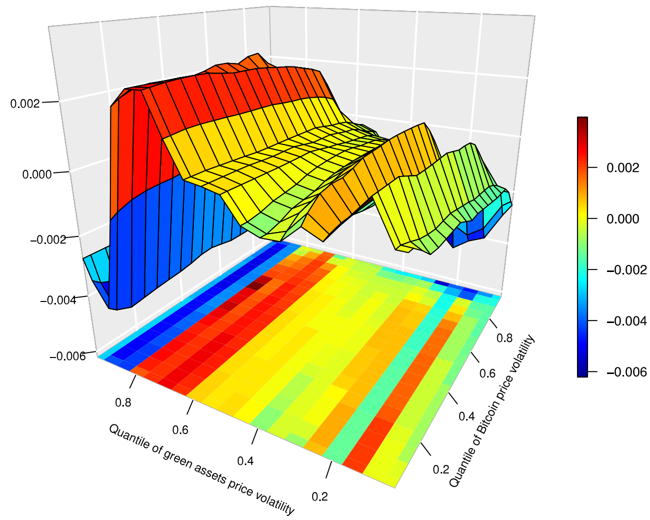
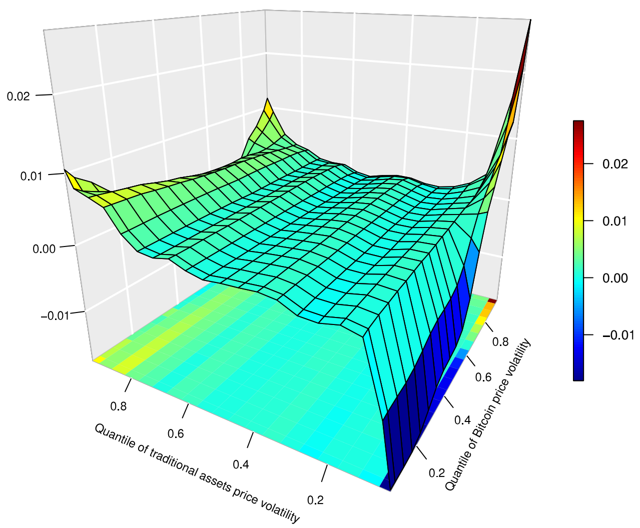


Fig. 1. QQ estimates for the impacts of Bitcoin return on green and traditional assets returns. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

respectively. Specifically, as for the channel of price return exhibited in Fig. 3, it is clear that the linkage of gold with both traditional and green assets either approaches to zero or negative across the joint data distribution, although featuring distinct patterns. The gold's correlation with green assets depicts a quasi-monotonic decreasing trend with decreases in quantiles of green assets while generally showing a similar pattern across quantiles of Bitcoin. Such the correlation tends to become negative and can be as low as −0.15 at extremely lower quantiles of green assets. This further implies the safe haven role of gold against green assets that their correlation could be even negative when the green market is in depression. At the same time, the correlation of gold with traditional assets could be relatively larger compared to that with green assets. The dynamics of the correlation over the distribution tend to be flatter and keep being weakly positive with the potential safe haven property of gold being relatively weak and only appearing at extremely low quantiles of traditional assets and extremely high quantiles of gold.



(a) Impact on green assets price volatility

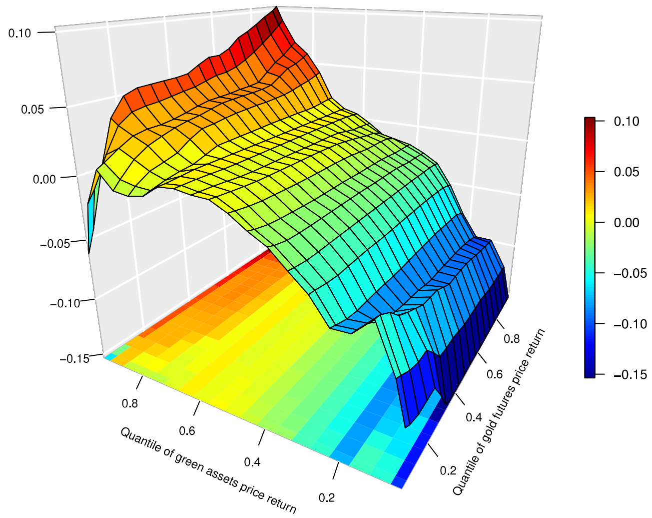


(b) Impact on traditional assets price volatility

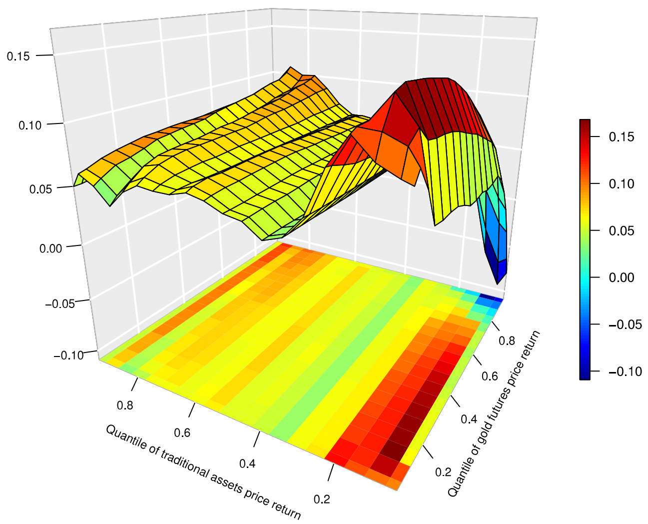
Fig. 2. QQ estimates for the impacts of Bitcoin volatility on green and traditional assets volatilities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

As for the channel of price volatility exhibited in Fig. 4, similar to the channel of price return, the dependence between gold and financial assets is weak or negative over various quantiles of the joint distribution. This indicates the sheltering role of gold for financial investment. The dependence exhibits a similar pattern for both green or traditional assets and features quasi-monotonic decreasing from high- to low-quantiles of the target asset. Noteworthy, the correlation of gold with financial assets keeps being weak or even negative during the financial turmoil, further depicting the safe haven role of gold. Overall, the result suggests that gold is a safe haven in bear market scenarios and a hedge against volatility in normal markets. This finding is in line with the studies of the view that gold can be considered as a safe haven asset is widely recognized, particularly in the depressed market environment by (see, e.g., Baur & Lucey, 2010; Beckmann et al., 2015; Wen et al., 2022).

Overall, through the above analysis under a full and joint distributional environment, our research confirms the asymmetric and nonlinear correlation between Bitcoin/gold and financial assets with the correlation pattern varies depending on the potential



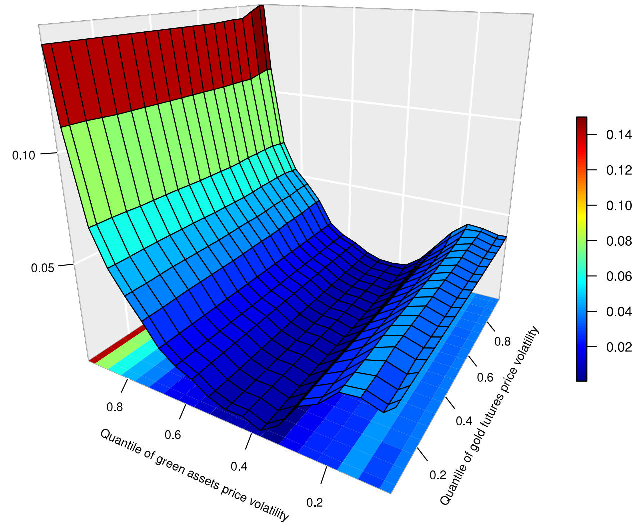
(a) Impact on green assets price return



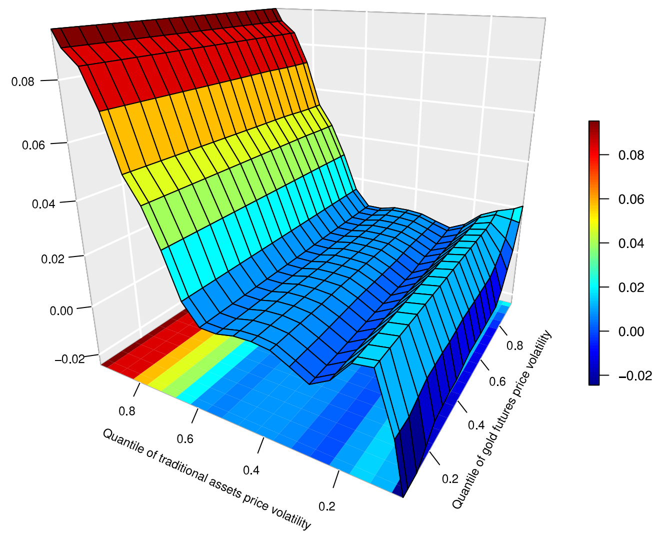
(b) Impact on traditional assets price return

Fig. 3. QQ estimates for the impacts of gold futures return on green and traditional assets returns. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

investment shelter (i.e., Bitcoin/gold) and target financial assets (i.e., green/traditional) across different quantiles over the data distribution. We further find that the effectiveness of both digital and traditional investment shelters tends to be greater for green assets as shown by a weaker or even more negative correlation degree than that for traditional assets. In addition, the digital shelter Bitcoin tends to be more effective compared to the traditional counterpart gold given that the dependence of Bitcoin with financial assets is relatively smaller or more negative. Our findings add to the ongoing debate in regard to the relationship of Bitcoin/gold with green and traditional assets. Consistent with the existing literature, such the relationship features evident asymmetry and nonlinearity over the data distribution (See, e.g., Hsu et al., 2021; Kamal & Hassan, 2022). While the investment sheltering role of both Bitcoin and gold is confirmed, the extent of the sheltering role features heterogeneity across different potential shelters and targets (i.e., green and traditional assets) (See, e.g., Bouri et al., 2020; Huang et al., 2021; Yan et al., 2022). In the next, we have conducted a series of additional analyses to confirm whether our findings are consistent when facing alternative estimation strategies, changes in estimation bandwidth, and sample stratification, respectively.



(a) Impact on green assets price volatility



(b) Impact on traditional assets price volatility

Fig. 4. QQ estimates for the impacts of gold futures volatility on green and traditional assets volatilities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

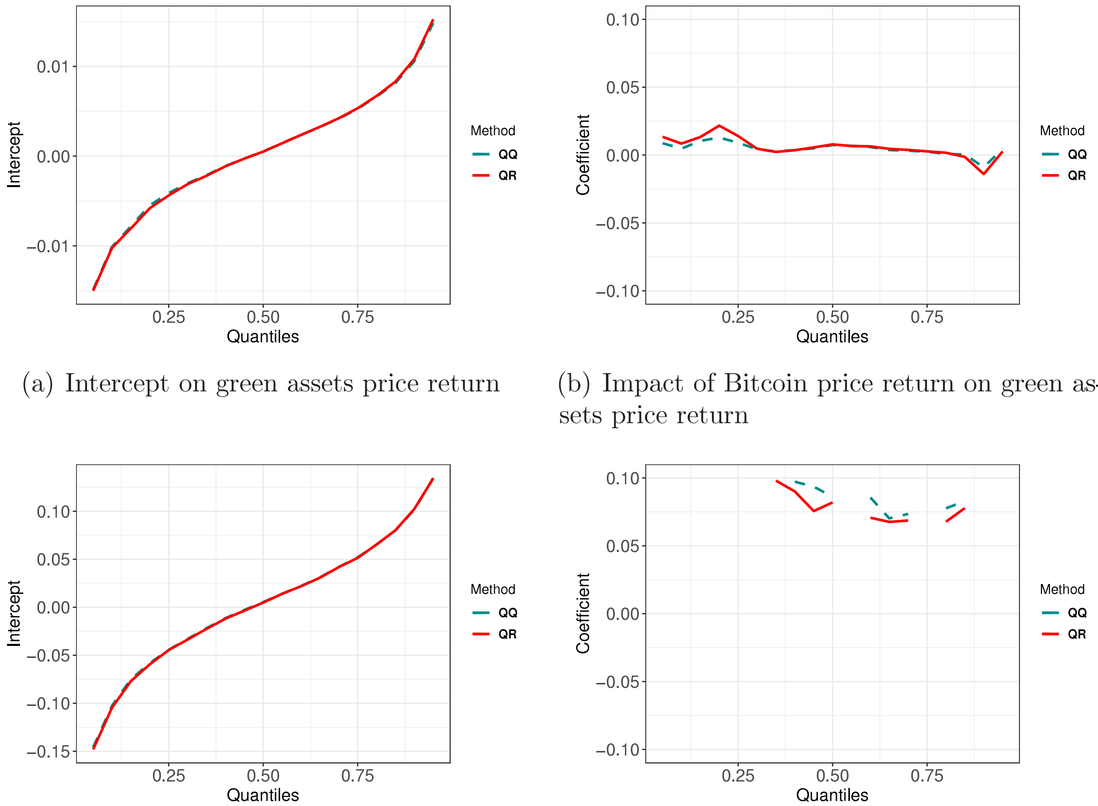
4.2. Additional analyses

4.2.1. Alternative estimation strategy: The τ- averaged QQ estimation

The QQ approach is shown to be effective in capturing marginal effects of a given explanatory variable at its different quantiles, and this approach can be viewed as a further decomposition of the traditional quantile regression (Sim & Zhou, 2015). To examine the robustness of our main findings obtained by the QQ method, the traditional quantile regression approach with τ-averaged QQ parameters is employed. The corresponding comparison of coefficient estimates between averaged QQ regression and the traditional quantile regression is shown in Figs. A.1–A.4.[4] It is clear that the estimates of the traditional quantile regression parameters, denoted

[4] To save space, results of the following robustness tests are in the Appendix.

by QR (continuous red line), are perfectly fitted with the averaged QQ estimation results (dotted blue line). It indicates that there exists no significant difference in the above comparison, confirming the robustness of our main findings.



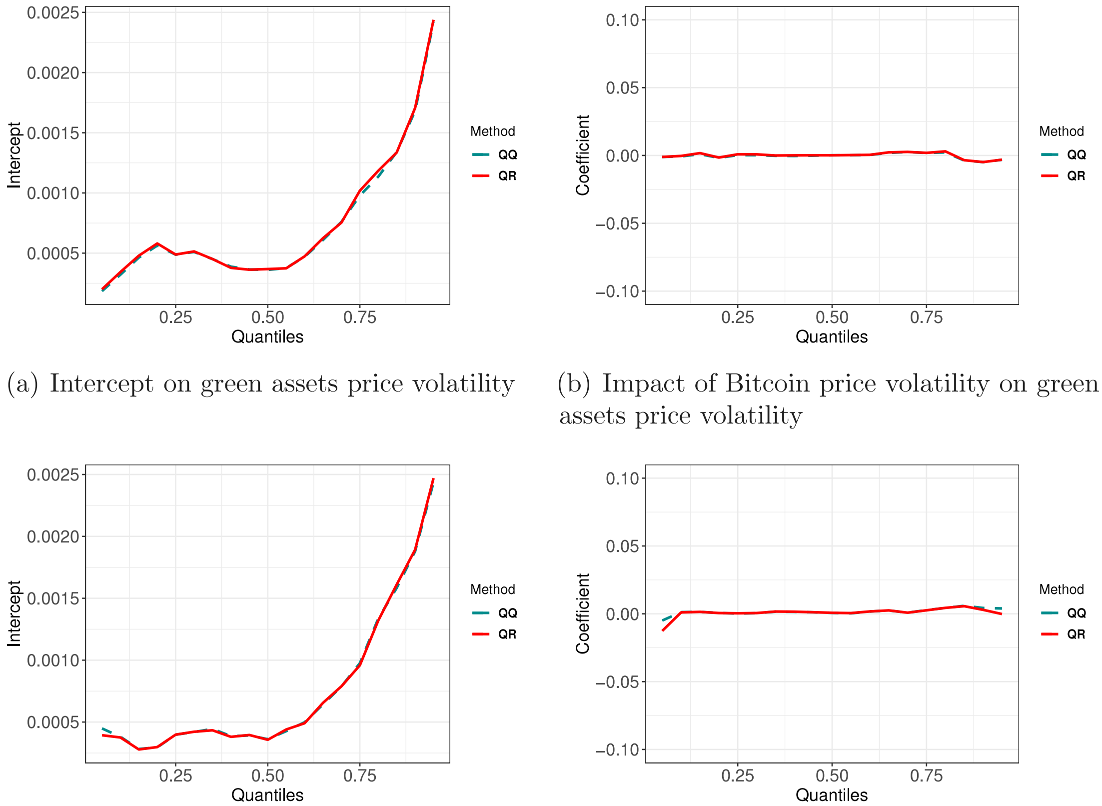
(a) Intercept on green assets price return

(b) Impact of Bitcoin price return on green assets price return

(c) Intercept on traditional assets price return

(d) Impact of Bitcoin price return on traditional assets price return

Fig. A.1. The robustness check 1: Comparisons of the results between the quantile regression and the QQ estimate (1). *Note:* The graph plots and compares the estimates of the traditional quantile regression parameters, denoted by QR (continuous red line), and the averaged QQ parameters regarding averaged impacts of Bitcoin price return on different quantiles of green and traditional assets price returns.



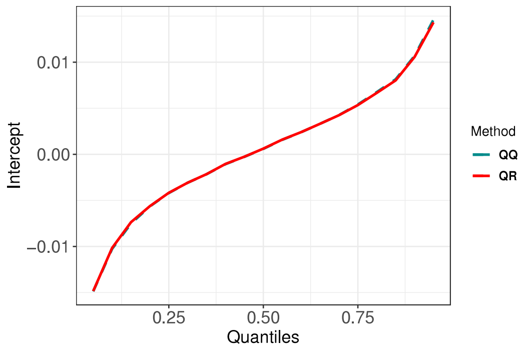
(a) Intercept on green assets price volatility

(b) Impact of Bitcoin price volatility on green assets price volatility

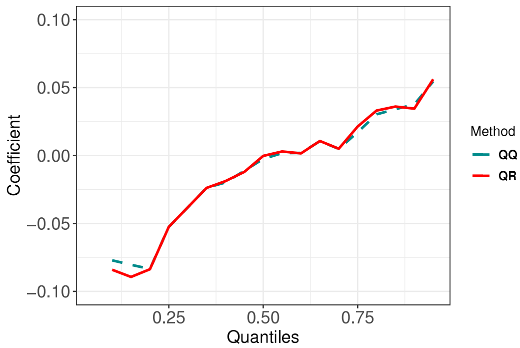
(c) Intercept on traditional assets price volatility

(d) Impact of Bitcoin price volatility on traditional assets price volatility

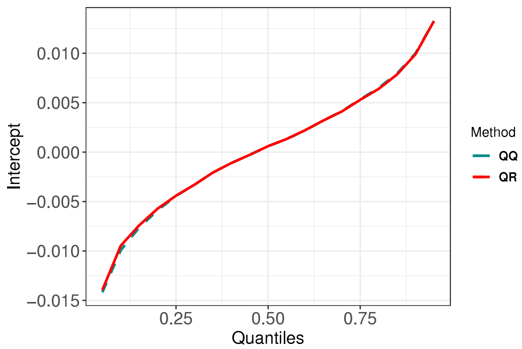
Fig. A.2. The robustness check 1: Comparisons of the results between the quantile regression and the QQ estimate (2). *Note:* The graph plots and compares the estimates of the traditional quantile regression parameters, denoted by QR (continuous red line), and the averaged QQ parameters regarding averaged impacts of Bitcoin price volatility on different quantiles of green and traditional assets price volatilities.



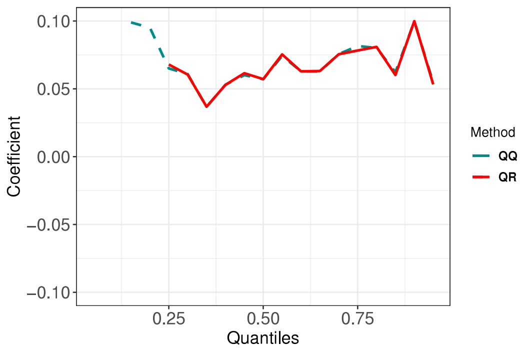
(a) Intercept on green assets price return



(b) Impact of gold futures price return on green assets price return

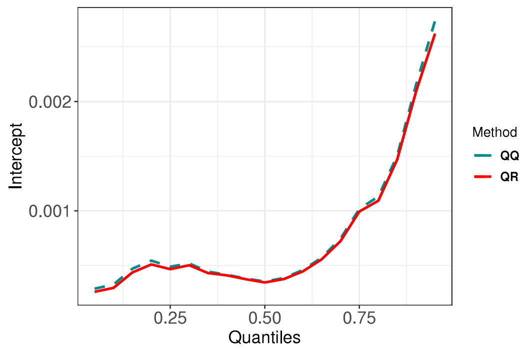


(c) Intercept on traditional assets price return

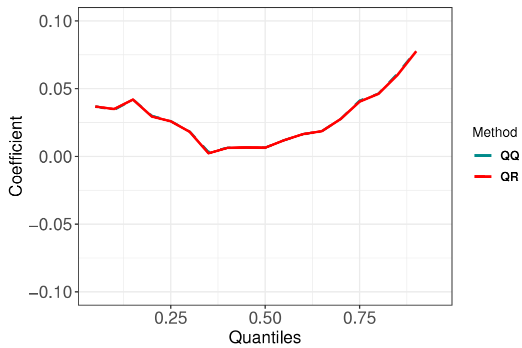


(d) Impact of gold futures price return on traditional assets price return

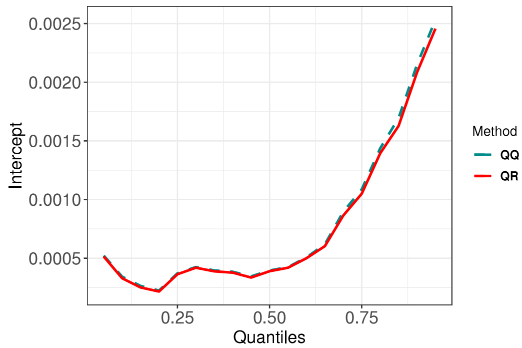
Fig. A.3. The robustness check 1: Comparisons of the results between the quantile regression and the QQ estimate (3). *Note:* The graph plots and compares the estimates of the traditional quantile regression parameters, denoted by QR (continuous red line), and the averaged QQ parameters regarding averaged impacts of gold futures price return on different quantiles of green and traditional assets price returns.



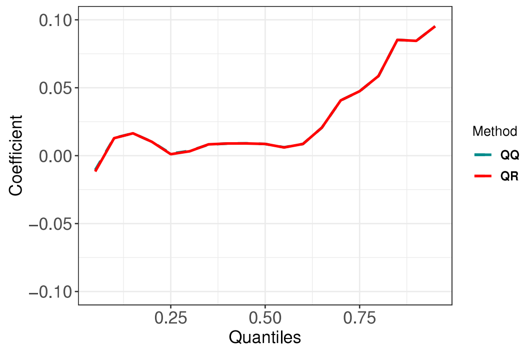
(a) Intercept on green assets price volatility



(b) Impact of gold futures price volatility on green assets price volatility



(c) Intercept on traditional assets price volatility

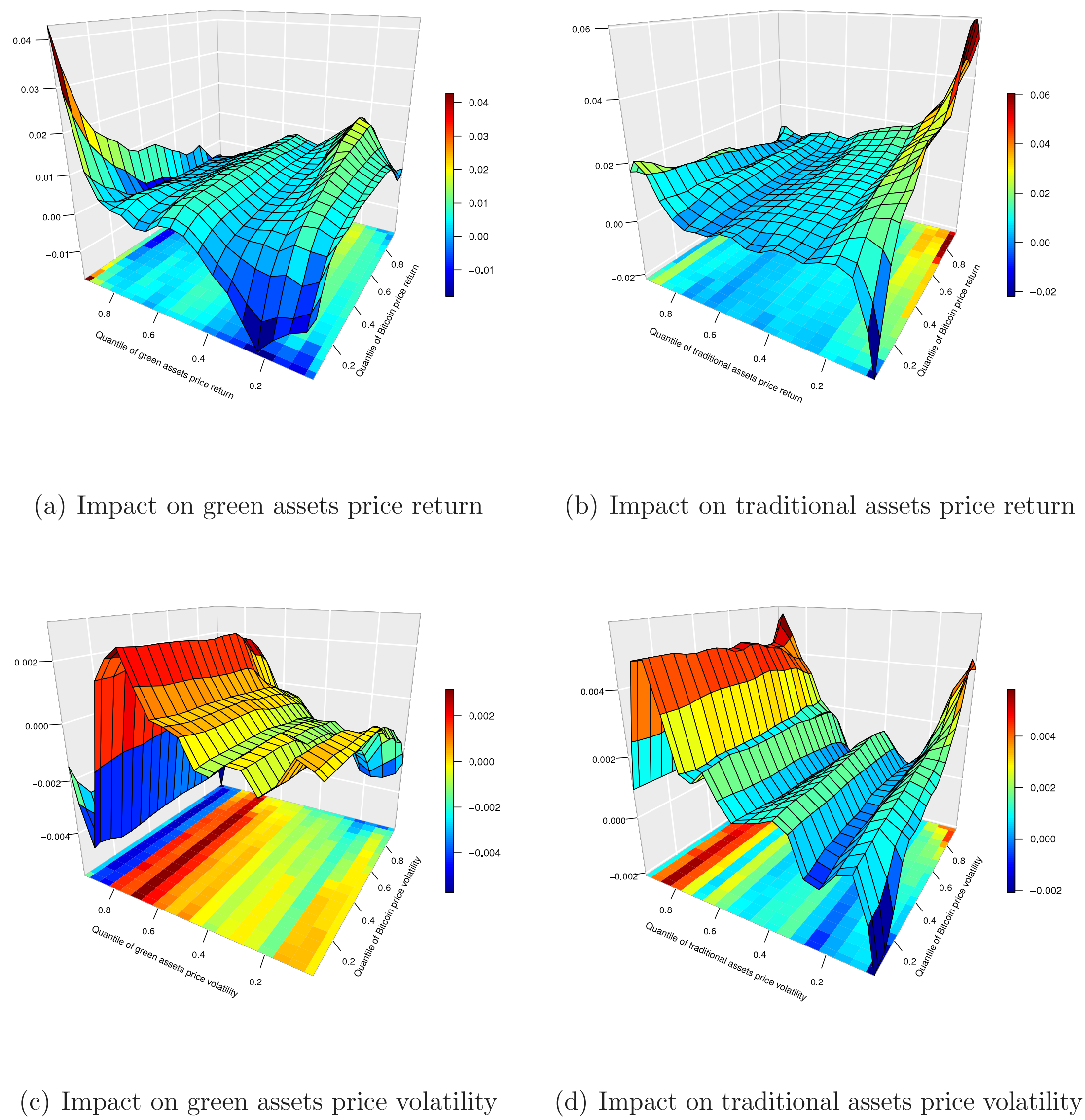


(d) Impact of gold futures price volatility on traditional assets price volatility

Fig. A.4. The robustness check 1: Comparisons of the results between the quantile regression and the QQ estimate (4). *Note:* The graph plots and compares the estimates of the traditional quantile regression parameters, denoted by QR (continuous red line), and the averaged QQ parameters regarding averaged impacts of gold futures price volatility on different quantiles of green and traditional assets price volatilities.

4.2.2. Changes in estimation bandwidth

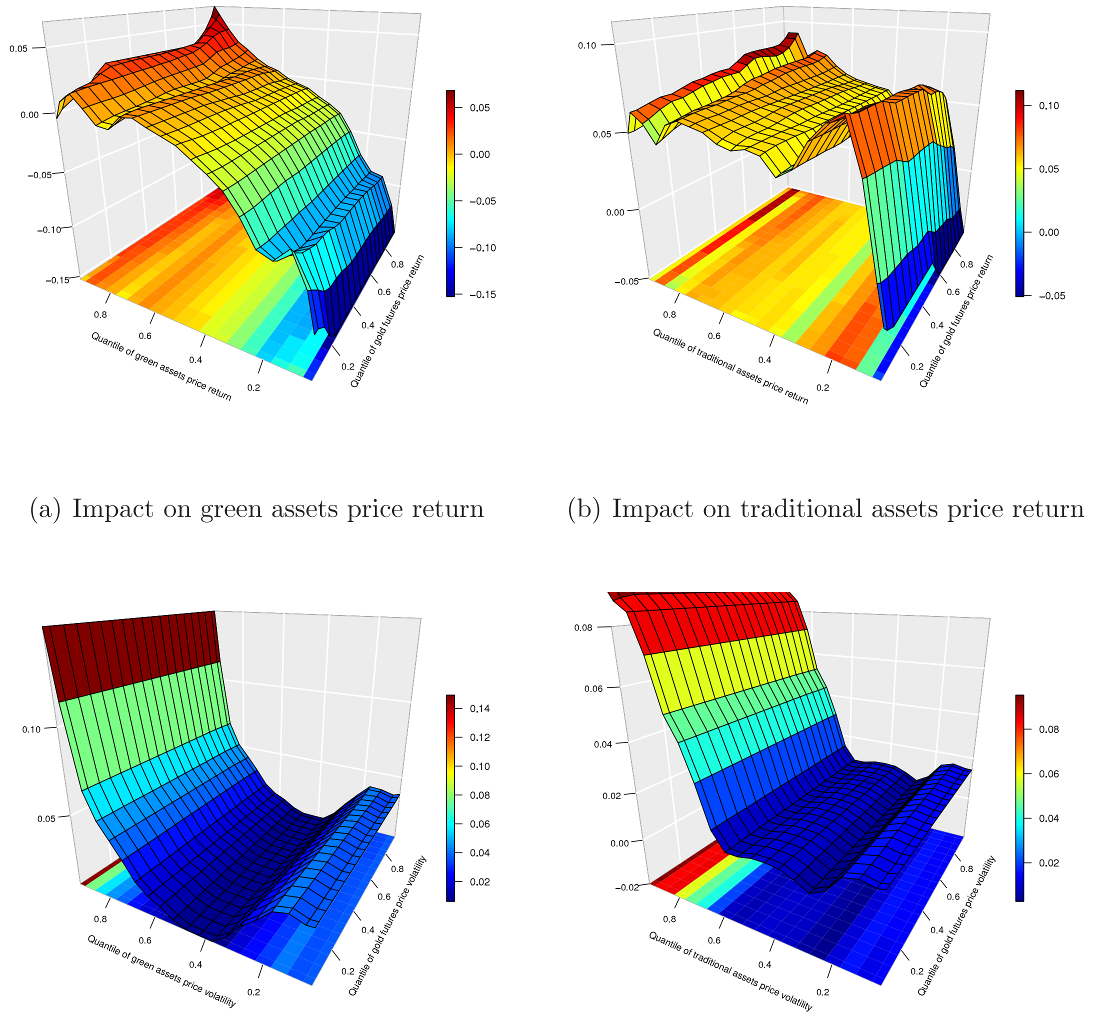
Regarding the selection of bandwidth for the QQ estimation, while our employed cross-validation (CV) method is known to outperform traditional methods given that CV considers the asymmetric data feature and minimizes the integrated estimation error (Duan et al., 2021b), we nevertheless change the selection method in a traditional fix-bandwidth setting. Through this, the robustness of our main findings can be further tested. Following the extant literature (See, e.g. Sim & Zhou, 2015), we choose a constant bandwidth (i.e., h in Eq. (3.4)) of 0.05, and re-conduct the QQ estimation. The corresponding results of the impacts of Bitcoin and gold on financial assets are reported in Figs. B.1 and B.2, respectively. It is clear that the obtained impact patterns from Bitcoin and gold to green and traditional assets from both perspectives of return and volatility broadly mimic that of our benchmark findings shown from Figs. 1 to 4, demonstrating the robustness of our results.



(a) Impact on green assets price return (b) Impact on traditional assets price return

(c) Impact on green assets price volatility (d) Impact on traditional assets price volatility

Fig. B.1. The robustness check 2: QQ estimates for the impacts of Bitcoin price return and volatility on green and traditional assets price return and volatility using a constant bandwidth, h = 0.05.



(a) Impact on green assets price return (b) Impact on traditional assets price return

(c) Impact on green assets price volatility (d) Impact on traditional assets price volatility

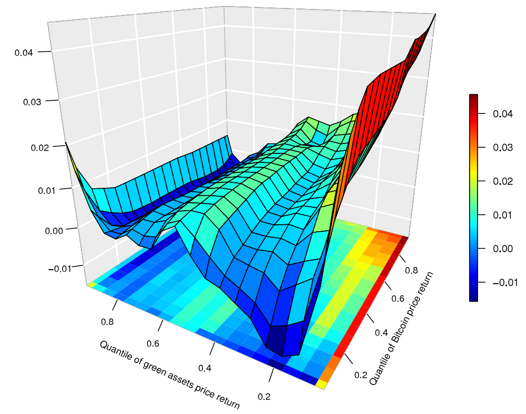
Fig. B.2. The robustness check 2: QQ estimates for the impacts of gold futures price return and volatility on green and traditional assets price return and volatility using a constant bandwidth, h = 0.05.

4.2.3. Sample stratification: Before and after the COVID-19 pandemic

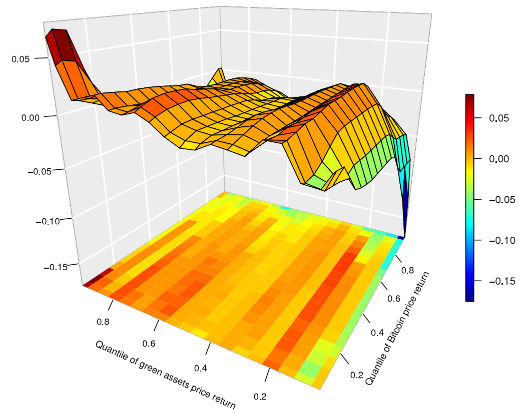
This section examines whether the sheltering role of Bitcoin is varied after having experienced extreme market conditions/shocks, i.e., the pandemic onset. Thus, we divide the samples into sub-samples before and after the COVID-19 outbreak. Overall, we find that while the investment sheltering role of Bitcoin exists irrespective of the pandemic onset, the extent of the role varies over time. At the same time, changes in the sheltering role of gold after the pandemic are also evident, particularly in the case of the cross-market impact measured by the price volatility. Specific findings are summarized as follows.

First, as shown in Fig. C.1, in terms of data in price return, prior to the outbreak of COVID-19, while Bitcoin generally depicted a negative correlation with green assets over most of the joint data distribution, such the correlation turns to be positive in lower quantiles of the green assets return. In contrast, after the pandemic, the majority impact of Bitcoin on green assets is a positive correlation but, surprisingly, such the impact became negative in a particular condition of extremely high Bitcoin quantile and extremely low green asset quantile. Moreover, Bitcoin can be identified as an evident hedge for traditional assets before the outbreak, while after the pandemic outbreak, the sheltering role of Bitcoin for traditional assets turns to be relatively unstable.

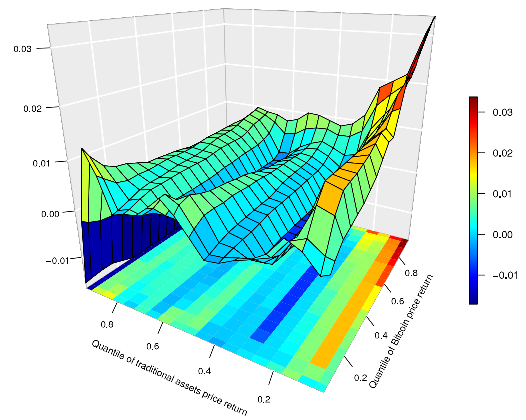
In terms of data in price volatility with the results shown in Fig. C.2, prior to COVID-19, Bitcoin had a negative impact on green assets when the latter is at extremely high quantiles, while the impact is found to be broadly close to zero, implying the hedging role of Bitcoin. After the outbreak of COVID-19, the impact pattern of Bitcoin on green assets reverses the impact is negative when green assets are at lower quantiles. Regarding traditional assets, the safe haven role of Bitcoin is found before and after the pandemic onset.



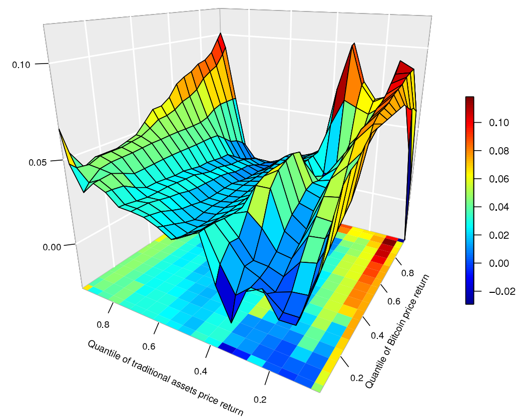
(a) Impact on green assets price return (before COVID-19)



(b) Impact on green assets price return (after COVID-19)



(c) Impact on traditional assets price return (before COVID-19)

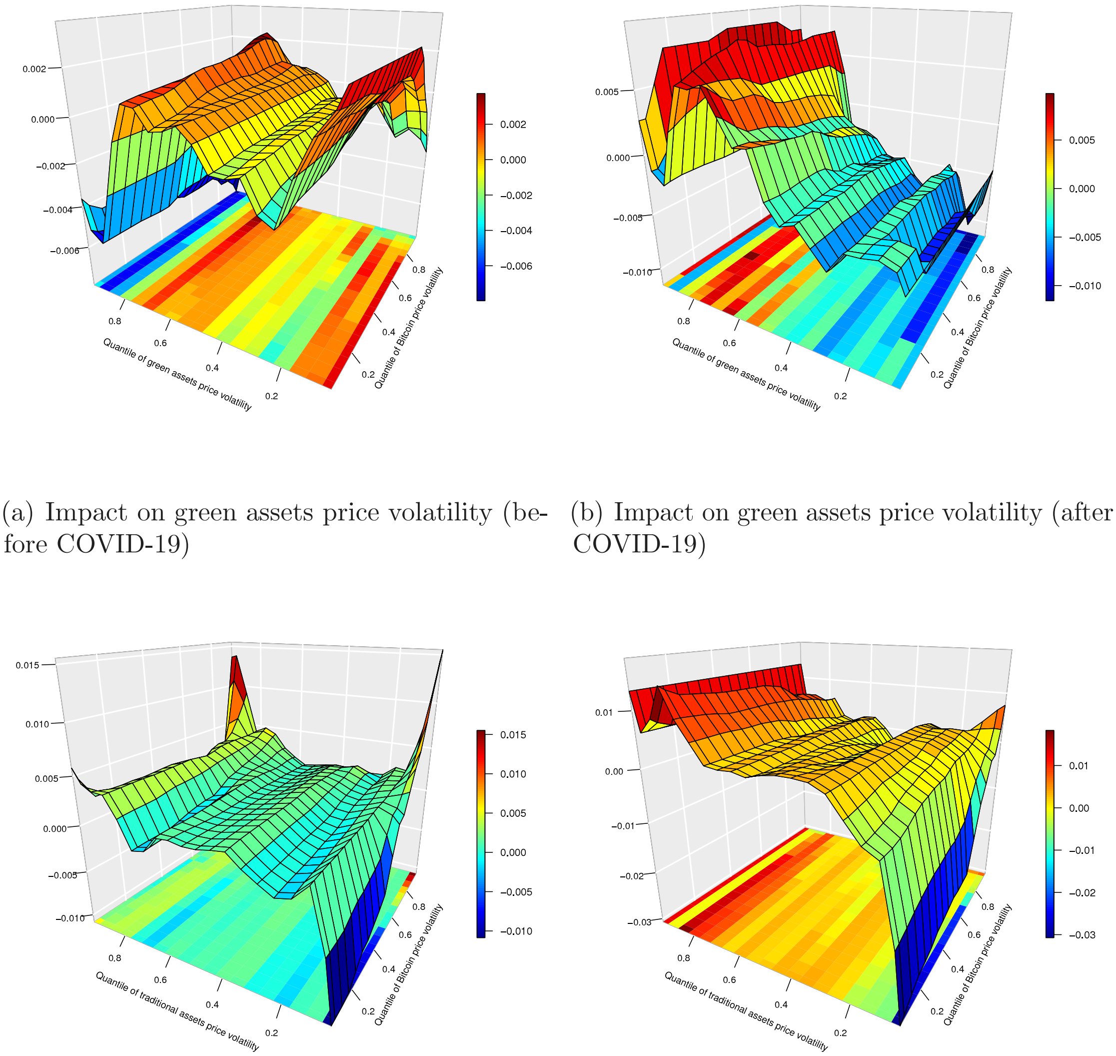


(d) Impact on traditional assets price return (after COVID-19)

Fig. C.1. The robustness check 3: QQ estimates for the impacts of Bitcoin price return on green and traditional assets returns in pre- and post-COVID-19 periods.

The magnitude of the impact after the pandemic is shown to be relatively greater than that before the pandemic across quantiles in the joint data distribution, indicating that the sheltering role of Bitcoin for traditional assets is stronger before the pandemic.

In parallel, as for the impact of gold in terms of data in return and volatility (depicted in Figs. C.3 and C.4), similar to that of Bitcoin, its impact differs due to the pandemic onset. However, the corresponding evolution of the impact pattern of gold is found to be different from that of Bitcoin. The above demonstrates the impact of the pandemic shock on changing the cross-market relationship between Bitcoin/gold and financial assets. The different impact pattern between Bitcoin and gold with financial assets is also examined.



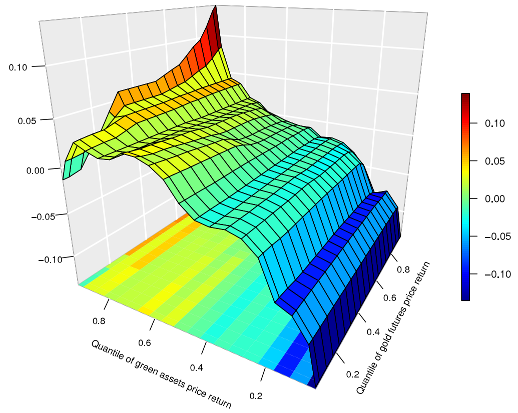
(a) Impact on green assets price volatility (before COVID-19)

(b) Impact on green assets price volatility (after COVID-19)

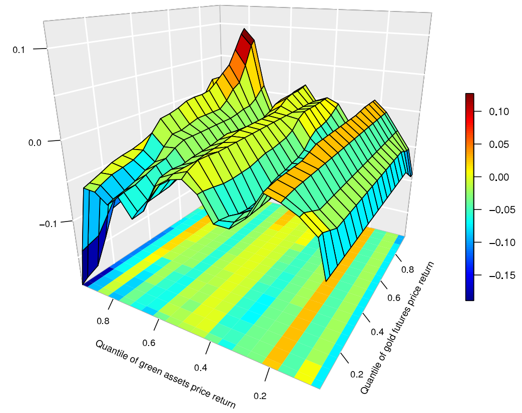
(c) Impact on traditional assets price volatility (before COVID-19)

(d) Impact on traditional assets price volatility (after COVID-19)

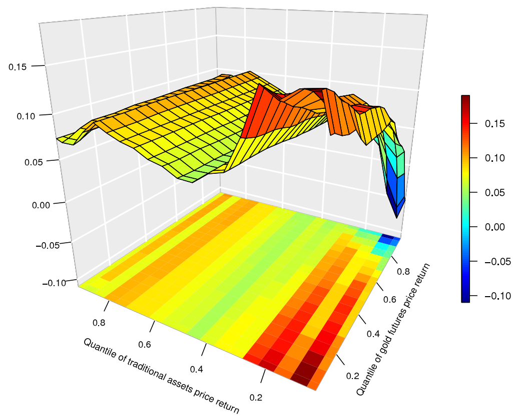
Fig. C.2. The robustness check 3: QQ estimates for the impacts of Bitcoin price volatility on green and traditional assets volatilities in pre- and post-COVID-19 periods.



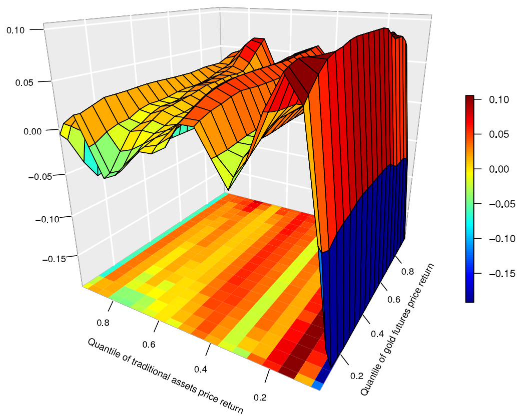
(a) Impact on green assets price return (before COVID-19)



(b) Impact on green assets price return (after COVID-19)

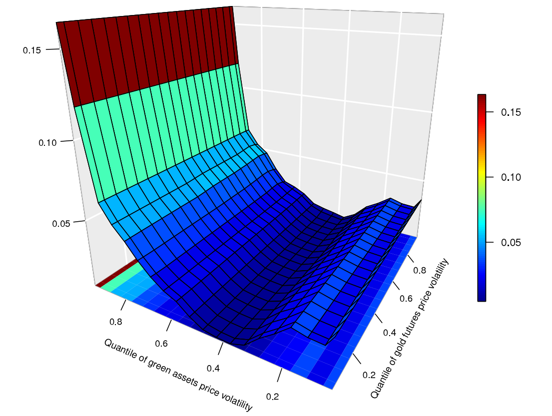


(c) Impact on traditional assets price return (before COVID-19)

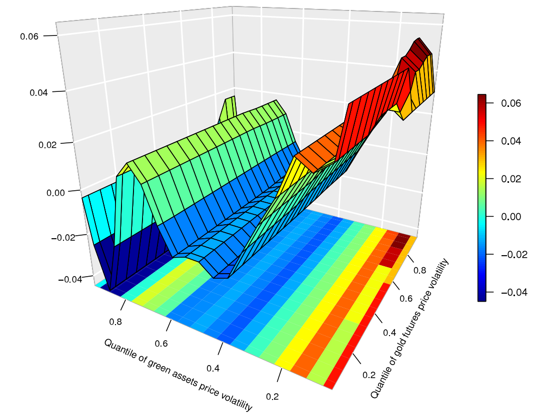


(d) Impact on traditional assets price return (after COVID-19)

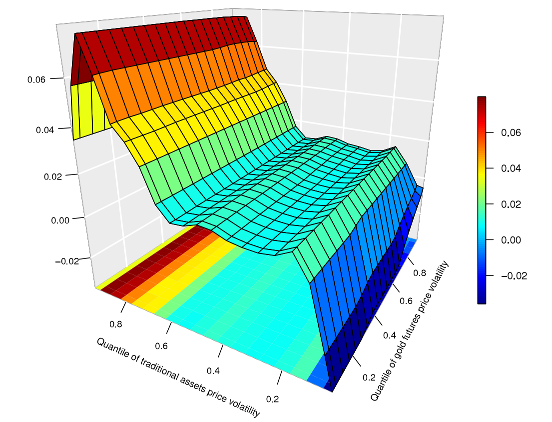
Fig. C.3. The robustness check 3: QQ estimates for the impacts of gold futures price return on green and traditional assets returns in pre- and post-COVID-19 periods.



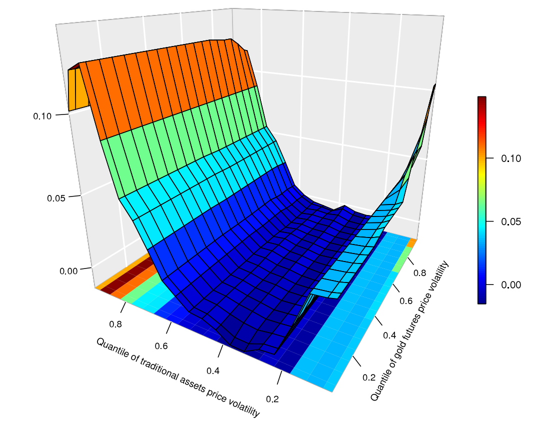
(a) Impact on green assets price volatility (before COVID-19)



(b) Impact on green assets price volatility (after COVID-19)



(c) Impact on traditional assets price volatility (before COVID-19)



(d) Impact on traditional assets price volatility (after COVID-19)

Fig. C.4. The robustness check 3: QQ estimates for the impacts of gold futures price volatility on green and traditional assets volatilities in pre- and post-COVID-19 periods.

5. Conclusion

Whether and how Bitcoin can play as an investment shelter against adverse fluctuations of both traditional and green assets? How different is the underlying sheltering role between Bitcoin and gold? To answer the above questions, this paper investigates the marginal dependence of Bitcoin with green and traditional assets in a full distributional setting established by a recently-developed quantile and quantile (QQ) method. The above impact of Bitcoin is compared with that of gold from both perspectives of data in return and volatility. Additional analyses such as results comparison between QQ and traditional quantile regression (QR), changes in estimation bandwidth, and sample stratification before and after the COVID-19 pandemic are further conducted to examine the robustness of the main findings.

Through a full and joint distributional analysis by the QQ estimation, several important findings emerge and are summarized on the following aspects. First, our results confirm the asymmetric correlation of Bitcoin/gold with financial assets. Such the asymmetry is captured from three perspectives, i.e., different quantiles of the data distribution, before/after the pandemic, and data in return and volatility, respectively. Second, the dynamics of the correlation vary depending on the potential investment shelter (i.e., Bitcoin/gold) and target financial assets (i.e., green/traditional) across different quantiles over the data distribution. Third, While Bitcoin can act as an investment shelter for different financial assets, its effectiveness for green assets is found to be stronger than traditional counterparts. Following the definition discussion by Baur and Lucey (2010), Bitcoin's sheltering role could be as either a diversifier, a hedge, and safe haven in different market conditions. Fourth, the investment sheltering role of Bitcoin tends to be stronger than that of gold given its relatively weaker or even more negative dependence with different financial assets, showing the good performance of Bitcoin in regard to diversification and risk mitigation.

Our findings provide a comprehensive investigation of the effectiveness of underlying investment shelters for various financial assets and offer important implications for various stakeholders. As for market investors, identifying the possible investment shelter for both green and traditional assets help in diversification and risk mitigation of their built financial portfolios under different market conditions, enhancing the portfolio management performance. In addition to traditional assets, the research also offers insights to explore effective sheltering instruments for the emerging and important green assets, being beneficial to the green economic transition. As for policymakers, our results help deepen their understanding on the role of the digital currency as potential investment shelters against both traditional and green financial assets, contributing to the stability of the economic and financial system. Indeed, identifying a safe haven instrument to adjust for market imbalances and accordingly developing appropriate and timely policy support are critical to the regulation of the systematic risk as well as the development of financial markets, especially during the period of financial turmoil.

CRediT authorship contribution statement

Kun Duan: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Yanqi Zhao:** Data curation, Software, Writing– original draft. **Zhong Wang:** Writing – review & editing. **Yujia Chang:** Formal analysis, Writing– original draft, Writing – review & editing, Project administration, Funding acquisition.

Data availability

Data will be made available on request.

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Appendix A. Results of robustness tests: Alternative estimation strategy

See Figs. A.1–A.4.

Appendix B. Results of robustness tests: Changes in estimation bandwidth

See Figs. B.1 and B.2.

Appendix C. Results of robustness tests: Sample stratification

See Figs. C.1–C.4.

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