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Gold and the herd of Cryptos: Saving oil in blurry times

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ABSTRACT

This paper assesses the effectiveness of a broad set of 1066 active and continuously traded cryptocurrencies as a safe haven instrument against extreme oil price movements, in comparison to the corresponding roles of gold. The uncertainty for the oil market during the COVID-19 pandemic and the subsequent Russia–Ukraine conflict set the tone for natural experiments for our study. We use a trail-blazing dynamic generalized autoregressive score model to estimate the tail riskiness of the potential safe haven assets from January 1, 2020, to September 30, 2022. By estimating the risk exposure of all cryptocurrency assets, we determine top ten safest assets for investment. Our results show the emergence of new safe haven cryptocurrencies, which have previously been ignored by the academic literature and policy makers alike. Intriguingly, our findings reveal that gold has been *replaced* by altcoins as the safest assets during both the COVID-19 pandemic and the Russia–Ukraine conflict. At this instance, our findings suggest that Bitcoin provides lengthier safe haven properties than gold for oil returns in both periods. However, the safe haven properties of gold and cryptocurrencies are time varying. Last but not least, we introduce a new *Cryptocurrency Tail Risk Index* (CTRI) that captures the risk exposure of cryptocurrency market, as a whole. Our results suggest that investment in numerous cryptocurrencies provides lengthier safe haven properties than investing in gold alone.

1. Introduction

The COVID-induced economic uncertainty[1] has led to a severe deterioration not only at the financial markets (see, among many, Ashraf, 2020; Baker et al., 2020; Gormsen and Koijen, 2020; Ramelli and Wagner, 2020; Zhang et al., 2020; Goldstein et al., 2021; Zaremba et al., 2021; Cheema et al., 2022), but also for energy markets (Dutta et al., 2020; Liao et al., 2021; Salisu et al., 2021; Zhang and Hamori, 2021; Akyildirim et al., 2022b; Dutta et al., 2022; Mensi et al., 2022; Ren et al., 2022a; Zhu et al., 2022; Duan et al., 2023). In the aftermath of the COVID-19 pandemic, especially the Russia-Ukraine conflict, renewed questions have been targeted on the safe-haven investment space for cryptocurrencies. Extant studies on the subject have mostly concentrated on the attribution of safe haven benefits for stock markets, whilst limited attention has been given on the energy markets, and in particular, the oil price movements. Besides, the existing studies have more often focused on traditional safe haven assets, such as gold, and to a lesser extent on the digital gold (Bitcoin), there is a sparse body of work focusing on the safe haven properties of other cryptocurrencies against oil price movements during the periods of market turmoil.

Undoubtedly, the COVID-19 pandemic has brought an imbalance between supply and demand for energy across countries causing high oil price volatility (Sharif et al., 2020). For high energy consuming industries that use oil as an input for production, their costs fall, profits surge, and share prices rise, but for others, such as energy supplying companies the fall in energy prices led to otiose profits, pushing numerous of them to exit the business (Foglia et al., 2022; González et al., 2022). To make things worse, the outbreak of the 2022 Russia–Ukraine conflict appeared to have further enhanced the volatility of energy prices, causing severe disruptions in the supply chains and restrictions in the availability of fossil fuels (Ahmed et al., 2022; Fang and Shao, 2022; Nerlinger and Utz, 2022). Investors often seek for safe haven assets to offset the energy commodity risk. Since future remains uncertain, and forecasts are difficult to make, energy markets are expected to face huge losses.

Traditionally, gold has long served as a risk management tool that maintain or appreciate in value during times of market turbulence (see for example, Baur and Lucey, 2010; Baur and McDermott, 2010, 2016;

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[1] Some authors term this as a phenomenon of *economic catastrophe* (Akhtaruzzaman et al., 2021a).

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Hood and Malik, 2013; Reboredo, 2013; Bredin et al., 2015; He et al., 2018; Ming et al., 2020; Mensi et al., 2021; Naeem et al., 2022). In recent years, numerous studies explore alternative assets that may act as safe haven and a large focus has been given to digital currencies, and in particular, Bitcoin (see, Selmi et al., 2018; Shahzad et al., 2019a; Urquhart and Zhang, 2019; Bouri et al., 2020a; Kwon, 2020; Shahzad et al., 2020; Huang et al., 2021; Huang et al., 2023). However, the results about the diversifying benefits of Bitcoin remain mixed (see, Conlon and McGee, 2020; Long et al., 2021; Baur et al., 2022; Kumar and Padakandla, 2022; Ren et al., 2022b; Wen et al., 2022; Li et al., 2023), and are often generalized for the whole cryptocurrency market. In fact, the existing literature has paid relatively little attention to the safe haven characteristics of alternative cryptocurrencies (altcoins) relative to oil price movements and has not extended this comparison beyond the initial phases of the pandemic, considering the 2022 Russia–Ukraine conflict. Our paper fills this gap in the flight-to-quality literature by answering the following questions: do cryptocurrencies serve as a safe haven against oil price movements during the COVID-19 pandemic, and beyond, after the outbreak of the 2022 Russia–Ukraine conflict? What is the risk exposure of altcoins, and how they rank compared to gold and Bitcoin? To address these questions, we consider a broad set of 1066 active and continuously traded cryptocurrencies, estimate their tail risk based on a trail-blazing dynamic generalized autoregressive score model, and assess their safe haven properties against oil price movements, relative to gold and Bitcoin.

The present study makes contributions to the literature at least on four aspects. First, this paper contributes to the fast growing literature on safe haven assets (Baur and Lucey, 2010; Baur and McDermott, 2010). The majority of studies in the field have been, to a great extent, focused on gold and Bitcoin, and merely a few consider its larger family of cryptocurrencies. In this paper, we consider a big data set of 1066 potential safe haven cryptocurrency assets, and then empirically examine their effectiveness toward oil price movements compared to gold. Beyond that, to facilitate the sudden and great increase of investors who search for safe haven assets, we evaluate the risk exposure of our cryptocurrency assets, and gold, and rank them along their safe haven properties to provide a robust comparison. Our results indicate the emergence of new safe haven cryptocurrencies, which have previously been ignored by the academic literature and policy makers alike. Intriguingly, our findings reveal that gold has been replaced by altcoins as the safest assets in the COVID-19 pandemic and the subsequent Russia–Ukraine conflict.

Second, this paper contributes to the small but gaining popularity literature on energy risk management (see, among others, Uddin et al., 2018; Huynh et al., 2020, 2021; Tiwari et al., 2020; Anwer et al., 2022; Uddin et al., 2022). Numerous studies in the literature have shown that oil price fluctuations have substantial effect on financial markets (Sadorsky, 1999). Consequently, it is essential to model the tail behaviour of oil price movements via an accurate tool for energy price risk management. Unlike some studies on the tail risk property of energy commodities statically based on the Value at Risk (VaR) or Expected Shortfall (ES), and their variations (Sadeghi and Shavvalpour, 2006; Fan et al., 2008; Marimoutou et al., 2009; Youssef et al., 2015; Laporta et al., 2018; Mehlitz and Auer, 2021), we measure the tail risk through the estimation of a joint dynamic model of ES and VaR. In fact, Yamai and Yoshiba (2005) demonstrate that the tail risk of VaR can cause serious problems in which ES can serve more appositely in its place. Roccioletti (2015) claims that ES is a coherent risk measure, whereas VaR ignores the shape and structure of the tail and, hence, is not a coherent risk measure as it fails the condition for subadditivity (Artzner et al., 1997, 1999; Danielsson et al., 2005). However, the ES fails the mathematical requirements for elicitability (Gneiting, 2011; Fissler and Ziegel, 2016). But the pair of ES and VaR is elicitable itself and, hence, subadditive, as shown by Acerbi and Székely (2014) and Fissler et al. (2016). To satisfy the elicitability property, our paper adopts the state-of-the-art model of Patton et al. (2019) that allows us to estimate ES jointly with VaR by minimizing the loss function. Thereupon, we are among the first to incorporate joint forecast of ES and VaR in the energy risk management literature.

Third, we introduce a new Cryptocurrency Tail Risk Index (CTRI) that captures the risk exposure of cryptocurrency market, as a whole. In contrasts to the current cryptocurrency indexes based on the news coverage data (see, Trimborn and Härdle, 2018; Anastasiou et al., 2022; Lucey et al., 2022; Wang et al., 2022), our new index relies on the actual trading data which cushion the impact of speculative nature of media over the index movements. The CTRI index aims to support the delivery of risk-informed investment by green investors, investors, and policymakers who make investment decisions, primarily in the financial sector. In this study, we utilize the CTRI index in aim to assess the potential safe haven property of cryptocurrencies against oil price movements. However, its applications are not limited to that and can go beyond, such as, in forecasting, market efficiency, risk management, climate finance, and so on, which further justifies the importance of the index introduced in this paper.

Last but not least, the existing studies in energy literature has been intensively focused on the context of the COVID-19 pandemic. This paper goes beyond and covers not only the period of the COVID-19 pandemic, but also the outbreak of the 2022 Russia–Ukraine conflict, which has notable impact on demand-supply chain in energy market. By doing so, we are one of the first to assess the usefulness of cryptocurrencies to act as safe haven for oil price movements in period of energy market turbulence.

The rest of the paper is organized as follows: Section 2 discusses methodological architecture pertaining to the estimation of conditional tail-risk for cryptocurrencies. Section 3 provides an overview of the data, whereas Section 4 presents and discusses the empirical results. Section 5 is devoted to sensitivity analyses. Section 6 concludes the paper with a summary of the main findings.

2. Literature review

With a promise to break away from central banks' intervention in the currency regulation, virtual currencies have created a remarkable pathway of growth - moving from a period of despondency to a sustained period of consolidation and expansion since their inception by Satoshi Nakamoto in 2008. Despite its general lack of embeddedness in asset pricing theory, investment proclivity in cryptocurrencies, especially in Bitcoin, has appeared to have broken the norm of a theory-backed prediction and has accepted in open arm the high-risk taking attitude for a handsome return. Since its astronomical rise in prices, Bitcoin and now a myriad other cryptocurrencies, have triggered an explosion of research – be it with regard to spillover effects (Corbet et al., 2019; Gillaizeau et al., 2019), quantification of memory and study of dynamic interdependence (Cheah et al., 2018) or sparsely, in-sample predictions (Catania et al., 2018; Borri, 2019).

A number of studies investigate the safe haven properties of cryptocurrencies and, in particular, Bitcoin (see, among other Selmi et al., 2018; Shahzad et al., 2019a; Urquhart and Zhang, 2019; Bouri et al., 2020a; Kwon, 2020; Shahzad et al., 2020; Huang et al., 2021). Several studies have examined the hedging capabilities of Bitcoin against other assets (Dyhrberg, 2016; Bouri et al., 2017; Baur et al., 2018; Fang et al., 2019; Urquhart and Zhang, 2019), the extreme value behaviour of Bitcoin (Osterrieder and Lorenz, 2017; Osterrieder et al., 2017; Maghyereh and Abdoh, 2020; Corbet et al., 2020), the efficiency of cryptocurrency market (Urquhart, 2016; Nadarajah and Chu, 2017), while the existence of bubbles in cryptocurrencies has been studied by Cheah and Fry (2015) and Corbet et al. (2018), among others. Bouri et al. (2017) determine Bitcoin as a poor hedge and is suitable for diversification purposes only. However, they find that Bitcoin is a great hedge and safe-haven when against extreme down movements in Asian stocks. Klein et al. (2018) analyse the nature of including Bitcoin in a portfolio and find no evidence of stable hedging capabilities. Pho et al. (2021) show that gold is a better portfolio diversifier than Bitcoin during the pre-COVID-19 pandemic times. Kumar and Padakandla (2022) find that gold is a better safe haven tool compared to Bitcoin against stock market turmoil, irrespective of timescales. Ren et al. (2022b) conclude that Bitcoin acts as an progressively enhanced safe haven for oil market crash with rises in the COVID-19 pandemic severity, while Bitcoin-oil price relationship reveals a gradual drop with spreads in intensity of the pandemic. Huang et al. (2023) find that the hedging role of Bitcoin for green assets is time varying and it is greater after the pandemic. Obviously, the literature has not reached a consensus on diversifying benefits of Bitcoin, which still remain mixed (see, Conlon and McGee, 2020; Long et al., 2021; Baur et al., 2022; Kumar and Padakandla, 2022; Wen et al., 2022; Li et al., 2023), and are often generalized for the whole cryptocurrency market.

More recently, the literature has started examining the hedge and safe haven behaviour of altcoins. Bouri et al. (2020b) analyse the hedging and safe haven properties of cryptocurrencies against the downside risk of U.S. equity market. They find that Bitcoin, Ripple and Stellar are safe-havens for all US equity indices, whereas Litecoin and Monero are safe-havens for the aggerate US equity index and selected sectors. With respect to Ethereum, Dash and Nem, they are hedges only for few equity sectors. Corbet et al. (2020) determine that Bitcoin is not isolated from traditional financial markets and, while it acts as a strong safe-haven for oil and a weak safe-haven for S&P500, it cannot be considered as either a weak or strong safe-haven for gold. The authors also find a bi-directional causal relationship between altcoins, namely Ripple, Ether, Stellar, Litecoin, Monero, Dash, and NEM, and Bitcoin. Mariana et al. (2021) find that both Bitcoin and Ethereum exhibit short-term safe-haven properties, however, Ethereum is potentially a better safe-haven than Bitcoin. Mensi et al. (2021) investigate dynamic frequency connectedness for volatility differences among eight cryptocurrencies: Bitcoin, Ethereum, Litecoin, Dash, Monero, Ripple, Nem and Stellar. They find that adding a cryptocurrency to a benchmark Bitcoin portfolio provides diversification benefits and reduces a downside risk, however, adding Bitcoin to a cryptocurrency portfolio does not offer diversification. Li et al. (2023) find that only meme coins can all act as safe-havens against bitcoin. Although the finance literature has made few attempts to investigate the safe haven properties of altcoins, the evidence is still limited. There is a need for further research of how they compare to the traditional safe haven assets such as gold and nowadays Bitcoin.

Gold has long standing popularity to act as safe haven in periods of market turmoil (see, for example, Baur and Lucey, 2010; Baur and McDermott, 2010, 2016; Bouri et al., 2020a). Baur and Lucey (2010) determine that gold acts as a safe haven, only for a limited time, for stock markets in the UK and the US but not in Germany. Baur and McDermott (2010) find that gold is a safe haven for the US and major European stock markets (including Germany) but not for Australia, Canada, Japan and the large developing markets. Hood and Malik (2013) find that platinum and silver do not serve as a safe haven for the US stock market but gold does. Creti et al. (2013) show that gold acts as a safe haven, but for oil, coffee, and cocoa correlations decline in times of downturns in stock markets. Similarly, Chkili (2016) and Mensi et al. (2018) find that gold is a safe haven for emerging stock markets during market turmoil. Bekiros et al. (2017) determine that gold is a safe haven for emerging stock markets in both crisis and non-crisis times. Klein (2017) finds that gold and silver serve as safe havens for developed stock markets but this characteristic is time varying. Rehman et al. (2019) also confirm that gold and silver provide maximum diversification benefits among a sample of nine different commodities, i.e., gold, silver, copper, platinum, palladium, wheat, crude oil, gas and coal. Peng (2020) finds that gold outperforms silver and platinum as a safe haven against Chinese stock market risk. However, the safe haven property of gold is found to vary across different financial and commodity markets.

Numerous studies find mixed evidence about the safe haven property of gold. Choudhry et al. (2015) show the gold lost its ability to act as a safe haven in the UK, the US and Japan during the Global Financial Crisis (GFC). Lucey and Li (2015) show that silver, platinum and palladium act as a safe haven for the US stocks at some periods when gold does not. Shahzad et al. (2019b) declare that gold does not act as a safe haven asset for G7 stocks, but Shahzad et al. (2020) determine the opposite for all G-7 markets but Canada. Further, Shahzad et al. (2019a) discover that Bitcoin and commodities exhibit a safe haven property against the Chinese stock market movements, whereas gold does not have such a property. Though, the evidence on the relevance of gold as a safe haven asset remains mixed, a further investigation is needed, especially, for times of extreme market downswings. Nguyen et al. (2020) show that gold futures are partially a safe haven for equity markets in the short-term, but not in the mid-term, whereas energy commodities play a hedging role in the 1990s.

The ability of gold and cryptocurrencies to act as safe havens have received an increased attention in the COVID-19 pandemic. Salisu et al. (2021) find that gold serves as a safe haven asset against oil price risks during the pandemic. Syuhada et al. (2022) determine that gold reduces the portfolio downside risk and, hence, serves as a safe haven, however, the safe haven ability of Bitcoin is inconsistent during COVID-19. Ustaoglu (2022) investigates the hedging and safe-haven properties of Bitcoin and Ethereum for emerging stock market indices. The author finds that during the COVID-19 period, Bitcoin and Ethereum have safe-haven features against most emerging stock market indices. Wen et al. (2022) find that gold is a safe haven for oil and stock markets during the COVID-19 pandemic, whereas Bitcoin is not. Concurrently, plentiful of current studies have questioned the view that gold and cryptocurrencies can act as a safe haven during turmoil. Conlon and McGee (2020) show that Bitcoin is not a safe haven for US stock market during the COVID-19 pandemic. Akhtaruzzaman et al. (2021b) show that gold acts as a safe haven numerous developed stock markets at the early stages of the COVID-19 pandemic, but its safe haven property is lost soon after. Both Hasan et al. (2021) and Cheema et al. (2022) find that gold serves as a safe haven for the US stock market during the GFC, but not in the course of COVID-19 turmoil. The former study shows that oil does not act as a safe haven at either time. Disli et al. (2021) show that neither gold nor oil exhibit safe haven characteristics during COVID-19 pandemic. Although the outcomes about the safe haven properties of gold and cryptocurrencies, mainly, Bitcoin during the COVID-19 pandemic remain mixed, we must acknowledge that a substantial number of studies explore the field. However, little to none research investigate whether gold and cryptocurrencies can act as safe haven assets during the 2022 Russia–Ukraine conflict, which is another global event brought extreme market movements, especially, for energy markets.

The outbreak of the 2022 Russia–Ukraine conflict enhance the volatility of energy prices, causing severe disruptions in the supply chains and restrictions in the availability of fossil fuels (Ahmed et al., 2022; Fang and Shao, 2022; Nerlinger and Utz, 2022). Ahmed et al. (2022) examine the effect of the 2022 Russia–Ukraine conflict on the European stock markets. The authors determine that during the event European stocks incurred a significant negative abnormal return. Fang and Shao (2022) examine the impact of the 2022 Russia–Ukraine conflict on the volatility of commodity markets. They find that the outbreak of the conflict result in a significant risk spillovers between the metal and energy markets, and a high volatility risk for commodities with a larger global share of Russian exports. Gaio et al. (2022) investigates the impact of the Russia-Ukraine conflict on the stock market efficiency of six developed countries. They find that stock markets are not efficient in times of crisis, and COVID-19 pandemic had more impact on market efficiency than the Russia-Ukraine conflict. Khalfaoui et al. (2023) use daily data for February 24, 2022–June 21, 2022 on Bitcoin, Ripple, Ethereum, and Litecoin, as well as the G7 stock markets to determine the existence of co-movements between War attention and cryptocurrencies. The authors find that under bearish and normal (bull) markets, War attention negatively (positively) affects all cryptocurrencies in short term. Nerlinger and Utz (2022) determine that energy firms outperform the stock market following Russian military intervention. Obviously, the existing literature explore the impact of the 2022 Russia–Ukraine conflict on various aspects of finance and economic perspective, however, searching for safe haven assets, especially in times of high energy market uncertainty, remains priority for policy makers and investors. Therefore, testing the safe haven properties of commodities, such as gold, and cryptocurrencies is worth investigating.

To summarise, past studies on safe haven assets concentrated on gold and, to a lesser extent, on cryptocurrencies, mainly, Bitcoin. However, the results from those studies are rather mixed on the safe haven properties of gold and Bitcoin for stock market investments. Nowadays, investors and portfolio managers may seek for assets that are considered to have safe haven characteristics in an attempt to protect their investments not only during the COVID-19 pandemic, but during any future crisis, such as the one caused by the 2022 Russia–Ukraine conflict. Hence, testing the safe haven properties of gold and cryptocurrencies, but also the altcoins and cryptocurrency market as a whole is worth investigating, and is what this paper does. The next section illustrates how we perform these tests.

3. Methodology

3.1. Measure of extreme risk

A main drawback for ES estimation is highlighted to be their failure on elicitability property, meaning that the ES cannot be estimated or evaluated directly (Gneiting, 2011). Recently, Fissler and Ziegel (2016) have shown that the pair of ES and VaR is elicitable itself and, hence, subadditive, and can be obtained from minimizing the loss function, L_{FZ0}:

$$L_{FZ0}(Y_t,\nu,e,\alpha) = -\frac{1}{\alpha e}\mathbf{1}\{Y_t \le \nu\}(\nu - Y_t) + \frac{\nu}{e} + log(-e) - 1 \tag{1}$$

where Y_t is the asset returns at time t, α is the probability level for the tail loss distribution, in our case, $\alpha = 0.05$, ν and e are the values of VaR and ES, respectively, and $\mathbf{1}$ is an indicator function which returns 1 when $Y_t \le \nu$ and 0 otherwise. As such, the asset returns do not affect the estimation if $Y_t > \nu$, but when $Y_t \le \nu$, forecasts of ES and VaR react to asset returns through the score variable.

To determine the tail riskiness of the assets, we adopt the dynamic joint one factor generalized autoregressive score (GAS—1F) model of VaR and ES introduced by Patton et al. (2019). The GAS-1F model outperforms its alternatives (Patton et al., 2019) and, therefore, we demonstrate our idea with this model. The major novelty in the model framework is the use of the scaled score to drive the time variation in the target parameter (see, Lazar and Xue, 2020, for a discussion). Particularly, we assume that both ES (e_t) and VaR (v_t) are driven by a common factor κ_t:

$$v_t = mexp\{\kappa_t\} \tag{2}$$

$$e_t = nexp\{\kappa_t\}, n < m < 0 \tag{3}$$

$$\kappa_t = \beta\kappa_{t-1} + \gamma H_{t-1}^{-1} s_{t-1} \tag{4}$$

where the forcing variable, $H_{t-1}^{-1}s_{t-1}$, is obtained from the FZ0 loss function, with I_t and s_t being the Hessian and score functions of the L_{FZ0}, respectively. Then, the score, s_t, and Hessian, I_t, are:

$$s_t = \frac{\partial L_{FZ0}}{\partial \kappa_t} = -\frac{1}{e_t}\left(\frac{1}{\alpha}\mathbf{1}\{Y_t \le v_t\}Y_t - e_t\right) \tag{5}$$

$$I_t = \frac{\partial^2 E_{t-1}[L_{FZ0}]}{\partial^2 \kappa_t} = \frac{\alpha - \kappa_\alpha m_\alpha}{\alpha} \tag{6}$$

where κ_α is a negative constant and $\alpha_\alpha \in (0,1)$. The Hessian, I_t, is constant so the scaling matrix, H_t, is set to one (see, Patton et al., 2019, for a discussion). Therefore, the GAS-1F model for ES and VaR is specified as:

$$\kappa_t = \beta\kappa_{t-1} + \gamma\frac{1}{nexp\{\kappa_{t-1}\}}\left(\frac{1}{\alpha}\mathbf{1}\{Y_{t-1} \le mexp\{\kappa_{t-1}\}\}Y_{t-1} - nexp\{\kappa_{t-1}\}\right) \tag{7}$$

3.2. Cryptocurrency tail risk index (CTRI)

Safe haven properties of the cryptocurrency markets are often recreated as those of a single cryptocurrency, such as Bitcoin, Ethereum, Ripple. However, since the onset of the COVID-19 pandemic, cryptocurrencies have increase in popularity not only as a good returnable investment, but also as safe haven assets in periods of market downturn. This momentum led to an upsurge in the number of the new crypto assets. As such, the dominance of already established crypto assets has been challenged. Here, we consider a broad set of 1066 active and continuously traded cryptocurrencies to create a new index that represents the tail riskiness of the cryptocurrency market, as a whole. Our index is one of a few purely based on actual numeric data, instead of news, as later may reflect speculative information which can have direct effect on the index fluctuations.

To construct the CTRI, we use the following formula:

$$CTRI = \sum_{i=1}^{1066} w_i|TR_i|, \qquad \text{where } w_i = \frac{MC_i}{\sum_{l=1}^{1066} MC_l} \tag{8}$$

where TR_i is the VaR tail risk of the individual cryptocurrency i; w_i is the weights share of the cryptocurrency i, where, $\sum w_i = 1$; MC_i is the market capitalization for i. In fact, the cryptocurrency weight w_i is calculated by dividing the market capitalization value of i by total market capitalization value for all 1066 cryptocurrencies. Then, there is a case where $i \equiv l$.

3.3. Safe haven model

In order to assess the safe haven properties of cryptocurrency and gold for oil price movements during market turmoil, we consider the following simple model:

$$Tail_t = \beta_1 + \beta_2 OIL_t + \varepsilon_t \tag{9}$$

where $Tail_t$ is the tail movement of the potential safe haven assets based on VaR GAS-1F model, OIL_t denotes the oil price returns at time t, and ε_t is the error term. Consistent with the past studies (Baur and Lucey, 2010; Baur and McDermott, 2010), if the estimated parameter β_2 in Eq. (9) is insignificant (regardless its sign) or positive significant, the asset can be determined as a safe haven for oil. Likewise, if β_2 is both negative and significant, then the asset does not act as a safe haven for oil.

The above model, i.e., Eq. (9), neglects the possibility that safe haven properties of an asset may vary over time. However, numerous studies have shown that cryptocurrencies may act as a safe haven in some periods but not others (Bouri et al., 2020b; Ji et al., 2020). To account for this, we extend Eq. (9) into a time-varying model. In fact, we estimate the following rolling-window regression:

$$Tail_{t,t+\xi} = \beta_1 + \beta_2 OIL_{t,t+\xi} + \varepsilon_{t,t+\xi} \tag{10}$$

where $Tail_{t,\,t+\xi} = Tail_t, Tail_{t+1}, \ldots, Tail_{t+\xi}$; $Oil_{t,\,t+\xi} = Oil_t, Oil_{t+1}, \ldots, Oil_{t+\xi}$; $\varepsilon_{t,\,t+\xi} = \varepsilon_t, \varepsilon_{t+1}, \ldots, \varepsilon_{t+\xi}$, where ξ is the size of the rolling window. The size of the rolling window is set to 40, consistent with past literature (Liu and Song, 2018; Enilov and Wang, 2021).

3.4. Time-varying robust Granger causality approach

To investigate the safe haven properties of gold and cryptocurrencies for oil price movements, we undertake a further check through the causality prism. In particular, we employ the time-varying robust

Granger causality method (TVP-GC) of Rossi and Wang (2019). The main advantage of TVP-GC method is that it is more efficient than the conventional Granger causality test in the presence of instabilities (see, Coronado et al., 2021; Balcilar et al., 2022). Given that our sample covers the periods of COVID-19 and the 2022 Russia–Ukraine conflict resulting in a destabilizing effect on energy markets, the TVP-GC method allows the investigation of time-varying causal relationship and, hence, it more robust than the standard Granger causality test in detecting causal patterns. Therefore, we consider the following bivariate VAR model with time-varying parameters:

$$y_t = \Theta_{1,t}y_{t-1} + \Theta_{2,t}y_{t-2}\ldots + \Theta_{p,t}y_{t-p} + \varepsilon_t \quad (11)$$

where $y_t = [y_{1,\ t}, y_{2,\ t}, \ldots, y_{n,\ t}]'$ is a $n \times 1$ vector, $\Theta_{j,\ t}$, for $j = 1, 2, \ldots p$ are functions of time-varying coefficient matrixes, p is the lag length, and ε_t are heteroscedastic and serially correlated idiosyncratic shocks, which are assumed to be heteroscedastic and serially correlated. The null hypothesis is tested that Tail (Oil) does not Granger cause Oil (Tail), i.e., $H_0 : \theta_t = 0$, for $\forall t = 1, 2, \ldots T$, where $\theta_t \subset (\Theta_{1,\ t}, \Theta_{2,\ t}, \ldots, \Theta_{p,\ t})$, against its corresponding alternative. The statistics to test the null hypothesis, following Rossi (2005), are: the exponential Wald (ExpW), the mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR) tests. The lag length of the VAR model is selected based on the Bayesian Information Criterion (BIC). Following the extant structural break literature, we choose a standard trimming parameter of 0.10 (see, Akyildirim et al., 2022a).

4. Data and preliminary statistics

To demonstrate and compare the safe haven properties of cryptocurrencies, with gold, for oil price movements in period of market turbulence, our dataset consists of daily closing prices in US Dollars from 31st December 2019 to 30th September 2022. The sample period starts at 31st December 2019, following the past literature, on which date cases of pneumonia detected in Wuhan, China, are first reported to the World Health Organization (see, Corbet et al., 2020; Zaremba et al., 2021). As a proxy for oil price, we use West Texas Intermediate crude oil prices (i.e., Crude Oil-WTI Spot Cushing U$/BBL), while for gold price, we use Gold Bullion LBM prices (i.e., Gold Bullion LBM $/t oz). The daily price data for gold and crude oil are obtained from Thomson Reuters Datastream database. All of the above series are calculated as log returns, Y_t, where $Y_t = (\ln(P_t) - \ \ln\ (P_{t-1})) \times 100$ for P_t is the closing price at day t.

Our dataset on cryptocurrencies is collected through the following rigorous procedure. First, we collect data on 9469 cryptocurrencies from www.coinmarketcap.com, which is a leading source for price and market capitalization data (see, Liu et al., 2022). Coinmarketcap.com incudes both defunct and active cryptocurrencies and, hence, mitigating survivorship bias (Huang et al., 2022). Second, we pre-select cryptocurrencies that have data series starting on or before 31st December 2019, in order to allow balance sample for comparison. Third, we exclude cryptocurrencies that are not active, i.e., are not existent as of 30th September 2022, or have discontinuity in trading during the sample period. Fourth, we exclude cryptocurrencies with market capitalization values of zero, as otherwise, this would create bias weights in our new index. Fifth, we exclude stablecoins, classified as such at coinmarketcap.com, from our analysis due to their in-built stability mechanisms (see, for a discussion, Katsiampa et al., 2022). As a result, our sample accounts for 77% of the total cryptocurrency market capitalisation as of 30th September 2022. Overall, the dataset comprises daily closing prices for 1066 cryptocurrency assets, including Bitcoin, with 1004 observations for each digital asset. All cryptocurrency series are calculated as log returns. Fig. 1 shows the daily values for the derived CTRI index based on tail risk estimation from the 1066 cryptocurrency assets over the period spanning January 2020–September 2022.

4.1. *Safest cryptocurrency assets during COVID-19 pandemic*

Table 1 presents the top 10 least risky cryptocurrency assets for investment based on the tail risk estimation. It can be seen that although Bitcoin is among the safest cryptocurrency assets, its first place has been challenged by other altcoins that outperform it and provide better safe haven properties. This is consistent with the previous literature, such as Mariana et al. (2021). Although the recent literature has noted that Bitcoin does not serve as safe have during extreme market conditions, such as COVID-19 pandemic (see, Ji et al., 2020; Conlon and McGee, 2020; Kumar and Padakandla, 2022), there is not yet concrete evidence of whether other cryptocurrencies can replace it as safe haven. In other words, the heterogeneous behaviour of cryptocurrency market is not yet well explored. In Table 1 we see that there are new cryptocurrencies, not yet investigated in the literature, that provide better safe haven properties than Bitcoin, and to others large cap cryptocurrency assets, such as Ethereum, Ripple, Litecoin, Bitcoin Cash. In that way, our finding adds to the pasts studies that focus and explore the safe haven properties on a particular group of cryptocurrencies, such as, Bouri et al. (2020b), Baur and Hoang (2021), Ren and Lucey (2022), Sarkodie et al. (2022). From policy perspective, our finding from Table 1 has advisory role for institutional investors not to focus only on large cap cryptocurrencies when constructing their portfolios but also to consider adding small cap cryptocurrencies in attempt to diversify risk and reduce the impact of adverse market conditions over their portfolio returns. In fact, our study is the first, to our knowledge, to rank and name the safest cryptocurrency assets during the COVID-19 pandemic based on big data from the whole cryptocurrency market.

4.2. *Preliminary analysis*

Table 2 presents the summary statistics of the daily series before and after the 2022 Russia–Ukraine conflict announcement. Table 2 indicates that cryptocurrencies are highly volatile before the outbreak of the 2022 Russia–Ukraine conflict, with mean returns being negative and ranging from −0.0042 for Shivers to −0.3695 for UNUS SED LEO, while for commodities, the mean returns are positive, and the greatest mean returns, of 0.2012, belongs to oil. After the 2022 Russia–Ukraine conflict announcement, oil, as well as, gold have lost their positive returnability stepping place to cryptocurrency assets, which now provide positive mean returns. In fact, the lowest mean return after the conflict outbreak is noted for oil prices. This is a signal that the energy markets are strongly affected by the global economic uncertainty. Besides that, the results from Table 2 suggest that gold has the lowest standard deviation of 1.0283, followed by CTRI of 1.1876, in pre-conflict times while after the outbreak of the 2022 Russia–Ukraine conflict, the cryptocurrency asset Kuai Token has a standard deviation of 0.6187 which is the lowest one, and is twice as less as the second one of gold. Therefore, the stable characteristics of gold prices are not persistent over time, and the same may be valid for the safe haven property of gold, as claimed by Cheema et al. (2022), which we investigate further later in this study. Last but not least, all series satisfy the stationarity condition as to augmented Dickey and Fuller (ADF) (Dickey and Fuller, 1979) and Fourier ADF by Enders and Lee (2012) unit root tests. The latter test is suitable in the presence of structural break(s) as it allows for an unknown number of level breaks.

Table 3 provides the correlation matrix between oil and its potential safe haven assets.[2] It can be noted that gold has the highest correlation with oil prices compared to all alternatives regardless the time period. The period of 2022 Russia–Ukraine conflict signifies gold as the only potential safe haven asset that exhibits positive correlation with oil returns. More precisely, gold returns have a coefficient of correlation of

[2] Full results from the correlation analysis are provided in Tables A.1 and A.2 at the Appendix.

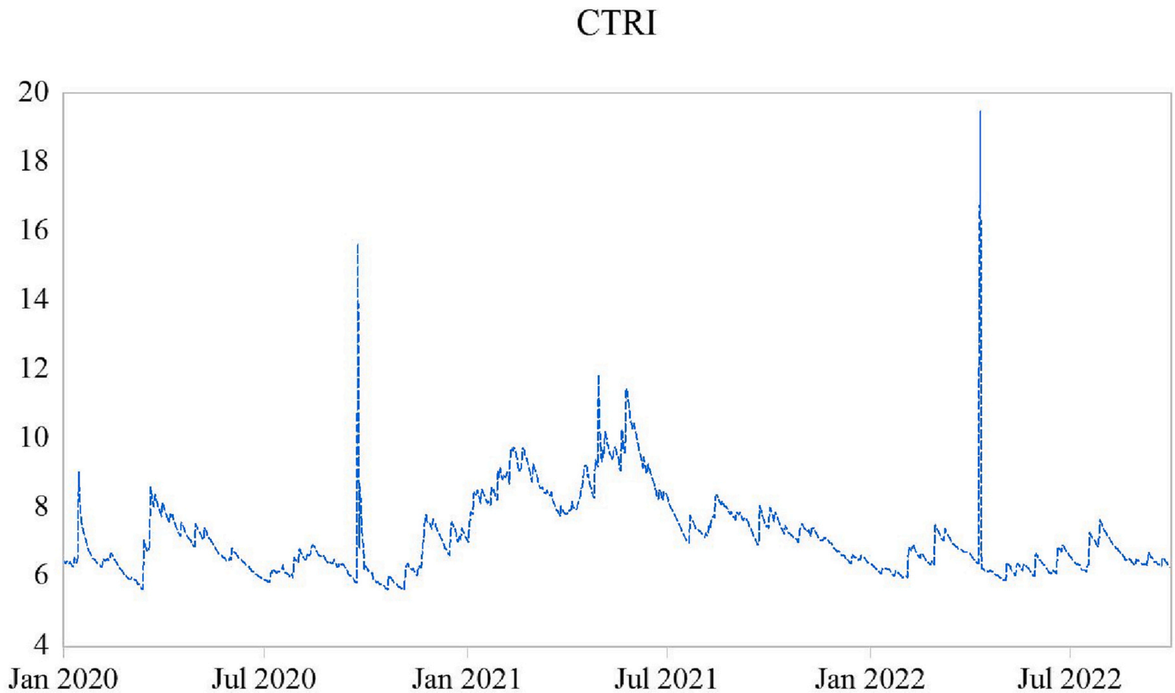

Fig. 1. Time-series graph of the CTRI index.

Table 1
Top 10 safest cryptocurrency assets.

Name	Symbol	Average loss	Rank
PAX Gold	PAXG	0.7431	1
UNUS SED LEO	LEO	1.9152	2
Cryptojacks	CJ	1.9289	3
ICOBID	ICOB	1.9624	4
Kuai Token	KT	1.9762	5
CrevaCoin	CREVA	2.0604	6
Shivers	SHVR	2.0902	7
Bitcoin	BTC	2.1535	8
Wrapped Bitcoin	WBTC	2.1539	9
IQeon	IQN	2.2213	10

Note: This table presents the top 10 safest cryptocurrency assets among a broad set of 1066 active and continuously traded cryptocurrencies. The tail risk for each asset is determined by the GAS-1F model.

0.4214 with oil price returns, which suggests rather close movements between gold and oil prices during the times of the energy uncertainty crisis. Besides that, it should be noted that PAXG has a negative correlation of −0.4556 with oil prices, whereas our newly constructed CTRI index has a coefficient of correlation −0.0876, which rank it on the 3rd place after the PAXG and KT among those with most negative correlation with respect to oil returns. Our findings from Table 3 suggest that cryptocurrency market provides better safe haven properties than gold against adverse oil price movements in times of energy market uncertainty.

5. Empirical results

To elicit our results better, we obtain the tail risk measures for each of the top 10 cryptocurrency assets listed in Table 1, as well as, gold, which allows us to firmly determine their riskiness and, hence, their safe haven characteristics for oil price movements. The tail risk measures are altered in absolute terms for simplicity of interpretation. We divide the entire COVID-19 sample into two sub-periods: pre-conflict announcement and post-conflict announcement. The sample is split into pre- and post-conflict announcement periods, as due by the date, 24th February 2022, on which Russia invaded Ukraine and determine the start of the Russia-Ukraine military conflict (see, Nerlinger and Utz, 2022). The pre-conflict announcement period starts from January 1, 2020 to February 23, 2022, while the conflict period covers 157 trading days starting from February 24, 2022 to September 30, 2022. The sample period covers the outbreak of the COVID-19 pandemic, thus enabling us to examine the performances of the potential safe haven assets during the COVID-19 outbreak, evaluate whether the outbreak of the Russia-Ukraine military conflict metamorphose the role of cryptocurrency and gold markets as a safe haven for energy market during episodes of market uncertainty.

As a robustness check, we assess the safe haven properties of our sampled assets by considering multi-horizon forecasts. In other words, we investigate if the safe haven features of our potential safe haven assets remain persistent over time or disappear.

5.1. Full sample analysis

Table 4 presents the results from the time-invariant safe haven models estimated on the cryptocurrency and gold tail risks against oil price returns. The table provides two set of results. In the first panel (Panel A), we show the estimated parameters from the pre-conflict announcement period, which overlaps with the COVID-19 pandemic times. It can be noted that all but one (two) assets have significant coefficient at 5% (10%) level. The other assets have insignificant coefficients which suggest that they are weak safe havens for oil price returns. In fact, only Bitcoin (BTC) and IQeon (IQN) are found to have significant coefficients, however, the sign of these coefficients is not the same. The coefficient for IQeon is significant but negative, which suggest that the particular crypto asset cannot be safe haven for oil price returns. But Bitcoin has a positive significant coefficient which suggest that it can act as a strong safe haven for the oil price returns in the pre-conflict times, and in particular, during the early stages of the COVID-19 pandemic. This finding is consistent with the findings of Hasan et al. (2021), but contradicts to Conlon and McGee (2020).

In the second panel (Panel B), we presents the results from the post-conflict announcement period. Here, all coefficients are found to be insignificant, which suggest that all assets are weak safe havens for oil price returns. This is quite surprising as in the pre-conflict times Bitcoin

Table 2
Summary statistics.

	Gold	Oil	PAX Gold	UNUS SED LEO	Cryptojacks	ICOBID	Kuai Token	CrevaCoin	Shivers	Bitcoin	Wrapped Bitcoin	IQeon	CTRI
Panel A: Pre-Conflict announcement													
Mean	0.0404	0.2012	−0.0226	−0.3695	−0.1608	−0.1813	−0.1347	−0.2050	−0.0042	−0.2685	−0.2723	−0.3309	7.3042
Std. Dev.	1.0283	4.4022	1.2096	3.9883	3.5012	3.5881	8.2265	3.6345	6.1691	4.4752	4.5065	4.1023	1.1876
Skewness	−0.7163	0.6890	0.3776	−2.9046	0.1070	−0.1763	−11.9158	−0.2384	10.6902	1.9446	2.1137	−1.0565	1.4015
Kurtosis	7.3475	20.9374	9.1144	36.2094	6.5454	7.6764	233.3112	7.6590	210.0897	24.5097	26.7250	12.5294	7.3892
ADF	−22.6371***	−21.0594***	−26.6625***	−26.7037***	−24.1534***	−23.933***	−25.1456***	−24.0681***	−22.8012***	−25.6794***	−25.8813***	−16.1853***	−3.3162**
Fourier ADF	−22.690***	−21.295***	−26.712***	−26.749***	−24.456***	−24.255***	−25.154***	−24.386***	−22.993***	−25.92***	−26.096***	−16.223***	−4.655***
Nº obs	561	561	561	561	561	561	561	561	561	561	561	561	561
Panel B: Post-Conflict announcement													
Mean	−0.0830	−0.0902	0.1078	0.1982	0.3017	0.3017	0.1059	0.3017	0.3017	0.3017	0.2996	1.5197	6.6338
Std. Dev.	0.9390	3.4395	0.9310	3.1118	4.0013	4.0008	0.6187	4.0013	4.0008	4.0008	4.0056	4.3602	1.1030
Skewness	0.0822	−0.4285	0.3006	0.6066	0.4879	0.4882	0.5071	0.4879	0.4882	0.4882	0.5028	0.4836	10.1805
Kurtosis	4.5339	3.8935	3.5953	7.3197	5.7377	5.7396	18.5552	5.7377	5.7396	5.7396	5.7244	5.3106	119.0203
ADF	−14.2497***	−12.2526***	−13.7486***	−18.4766***	−12.7197***	−12.7181***	−17.8513***	−12.7197***	−12.7181***	−12.7181***	−12.7688***	−12.8821***	−11.5245***
Fourier ADF	−14.508***	−7.365***	−10.466***	−18.543***	−7.745***	−7.745***	−18.224***	−7.745***	−7.745***	−7.745***	−7.728***	−13.173***	−12.107***
Nº obs	157	157	157	157	157	157	157	157	157	157	157	157	157

Note: This table presents the summary statistics of the ten cryptocurrency return series, gold returns and the CTRI index over the pre- and post-conflict announcement period. The table has two panels, A and B, corresponding to pre- and post-conflict announcement periods, respectively. It reports the mean returns (Mean), standard deviation of the returns (Std. Dev.), skewness (Skewness), kurtosis (Kurtosis) and the number of observations (Nº obs). The table reports the test statistics from ADF and Fourier ADF tests. The ADF tests has a null hypothesis of a unit root, against its corresponding alternative, while Fourier ADF test has a null hypothesis of a unit root series with the unknown number of level breaks, while the alternative hypothesis is of the stationary process with the unknown number of level breaks. The lag length is selected by using the BIC. **,*** denote statistical significance at the 5% and 1% level, respectively.

Table 3
Correlation matrix between oil returns and its potential safe haven assets.

	Panel A: Pre-Conflict announcement	Panel B: Post-Conflict announcement
Gold	0.0525	0.4214
PAX Gold	−0.1054	−0.4556
UNUS SED LEO	0.0219	−0.0648
Cryptojacks	−0.0244	−0.0762
ICOBID	−0.0232	−0.0762
Kuai Token	−0.0036	−0.1435
CrevaCoin	−0.0187	−0.0762
Shivers	−0.0153	−0.0762
Bitcoin	−0.1525	−0.0762
Wrapped Bitcoin	−0.1440	−0.0759
IQeon	−0.0881	−0.0629
CTRI	0.0394	−0.0876

serves a strong save haven, which suggests that its safe haven ability weakens in times of increased energy market uncertainty. In that way, we can conclude that cryptocurrencies and, in particular, Bitcoin have asymmetric save haven behaviour for oil returns that is changing over time. This finding provides a further support to Ji et al. (2020), who investigate the safe haven role of some traditional asset types on stock markets movements and conclude that safe haven property is changing over time and is sensible to the choice of markets. In terms of other potential safe haven assets, we conclude that their safe haven behaviour remains unchanged in the conflict period considering 5% level of significance results.

Overall, from both panels in Table 4, it can be noted that the CTRI index as a representative of the tail risk in the whole cryptocurrency market suggests that cryptocurrencies can provide a weak safe haven for oil price returns in both pre- and post-conflict announcements periods. This implies that cryptocurrency market, as a whole, is only a weak safe haven for oil price returns during the COVID-19 pandemic. The same can be concluded for gold, which is found to exhibit only weak safe haven properties for oil price returns in either periods. The latter finding is partially consistent with Wen et al. (2022) who find that gold serves as a safe haven for oil markets, but they could not find such evidence for Bitcoin. Nonetheless, we find that Bitcoin but no other assets serve as a strong safe haven for oil market when the pandemic critically spreads, specifically, at its early stages. The latter is consistent with Ren et al. (2022b) who conclude that the Bitcoin-oil price relationship exhibits a gradual drop with increases in intensity degrees of the COVID-19 pandemic. Intriguingly, our results determine that the onset of the 2022 Russia–Ukraine conflict could not trigger a strong safe haven properties in either gold or digital crypto assets for oil market. However, these results may be sensitive to structural instability in the estimated parametric models, therefore, the next section explores the potential time varying nature of the safe haven properties of cryptocurrency and gold for oil price movements.

5.2. Time varying estimation

Table 5 shows the percentage frequency from rolling-window safe haven regressions on the cryptocurrency and gold tail risks against oil price returns. The table reports the percentage frequency of significant negative coefficients β_2 from Eq. (10) in terms of 5% and 10% levels of significance. The percentage frequency is calculated as the total number of negative significant coefficients β_2 is divided by the total number of tests. For example, the percentage frequency for gold at 10% significance level is 0.054. This implies that 5.4% of all coefficients β_2 are both negative and significant and thus gold does not act as a safe haven for the oil prices returns at 5.4% of the cases. The results are further divided into two panels: pre- and post-conflict announcement periods.

In panel A of Table 5, we present the results from the pre-conflict announcement period. The results suggest that CTRI index has the

Table 4
Full sample estimates and relevant statistics.

	Gold	PAX Gold	UNUS SED LEO	Cryptojacks	ICOBID	Kuai Token	CrevaCoin	Shivers	Bitcoin	Wrapped Bitcoin	IQeon	CTRI
Panel A: Pre-Conflict announcement												
β_2	0.0009	0.0033	−0.0084	0.0024	−0.0001	0.0384	−0.0041	−0.0018	0.0164	0.0176	−0.0368	0.0106
(s.e)	0.0009	0.0113	0.0273	0.0357	0.0233	0.0521	0.0104	0.0173	0.0072	0.0109	0.0217	0.0078
p-value	0.3291	0.7716	0.7581	0.9469	0.9951	0.4608	0.6943	0.9156	0.0226	0.1054	0.0906	0.1748
Panel B: Post-Conflict announcement												
β_2	0.0010	0.0008	−0.0341	−0.0033	−0.0061	0.0947	−0.008	−0.0066	0.0006	0.0013	0.0208	−0.0281
(s.e)	0.0015	0.0090	0.0551	0.0134	0.0112	0.0861	0.0072	0.0075	0.008	0.0125	0.0276	0.0316
p-value	0.4947	0.9323	0.5361	0.8032	0.5847	0.2712	0.2624	0.378	0.9435	0.9167	0.4503	0.3731

Note: This table presents the β_2 coefficients from Eq. (9) and their relative statistics, to determine the safe haven properties of our sampled assets for oil price movements. The table has two panels, A and B, corresponding to pre- and post-conflict announcement periods, respectively. The second and third rows in each panel corresponds to the standard error (s.e.) and probability value (*p*-value) for each coefficient.

Table 5
Percentage frequency from rolling-window safe haven regressions on the cryptocurrency and gold tail risks against oil price returns.

	Panel A: Pre-Conflict announcement		Panel B: Post-Conflict announcement	
	5%	10%	5%	10%
Gold	0.027	0.054	0	0
PAX Gold	0.017	0.033	0	0
UNUS SED LEO	0.063	0.080	0.017	0.068
Cryptojacks	0.010	0.036	0	0
ICOBID	0.013	0.040	0	0.008
Kuai Token	0.010	0.015	0	0
CrevaCoin	0.034	0.052	0	0.008
Shivers	0.006	0.017	0	0
Bitcoin	0.008	0.015	0	0.008
Wrapped Bitcoin	0.008	0.017	0	0
IQeon	0.015	0.044	0	0
CTRI	0.006	0.008	0	0

Note: The table reports the percentage frequency of significant negative coefficients β_2 from Eqs. (10), based on 5% and 10% level of significance. The percentage frequency is calculated as the total number of negative significant coefficients β_2 is divided by the total number of rolling window tests.

lowest percentage frequency, of 0.008 at 10% level of significance, among all potential assets. While, at 5 level of significance, CTRI remain its first place but this is shared with the Shivers (SHVR), who both have percentage frequency of 0.006. At the same time, the asset that provides the worst safe haven properties is UNUS SED LEO (LEO) considering either level of significance. Surprisingly, gold has percentage frequency of 0.027, at 5% significance level, which lists it as the third worst asset based on safe haven properties. This results becomes even worse when considering 10% level results where gold climb up to the second place with percentage frequency of 0.054. Therefore, we can conclude that cryptocurrency assets contain overall better safe haven properties than gold in the COVID-19 times.

The results from the 2022 Russia–Ukraine conflict period, given in Table 5, panel B, suggest that all assets but UNUS SED LEO are equally important safe havens for oil price movements considering 5% level of significance. Results from 10% level are rather similar with the exception that few cryptocurrencies exhibit non-safe haven properties at 0.8% of the cases, i.e., ICOBID (ICOB), CrevaCoin (CREVA) and Bitcoin. Comparatively, the later finding may suggest that gold has slightly better safe haven properties than Bitcoin during the conflict times. However, the cryptocurrency market, as a whole, represented by the CTRI index, act as good as gold as safe haven asset for oil market. Overall, we can conclude that both cryptocurrencies and gold improve their safe haven properties against oil market risks in times when the energy market experience high uncertainty.

In general, the results from Table 5 lead to the conclusion that cryptocurrencies as a whole can act as safe haven for oil market in both times of COVID-19 and after the onset of the 2022 Russia–Ukraine conflict. Gold exhibit more persistent safe haven properties when the energy market uncertainty increases due to a military conflict, but rather weaker safe haven properties compared to cryptocurrencies when considered the period of early stages of the COVID-19 pandemic. The later finding has implications for institutional investors who may consider including cryptocurrency assets in their portfolios in an attempt to offset potential negative effect from oil market movements on their portfolio returns in the presence of major public health emergencies or a military conflict.

5.3. Granger causality test results

To further examine the safe haven properties of cryptocurrencies and gold for oil market, we employ a battery of Granger causality tests. First, we employ a standard time-invariant Granger causality test. If an evidence of causality from oil returns to the potential safe haven asset is determined, this signifies that the asset is not a safe haven for oil market because it reacts to oil price movements and, in particular, it is exposed to oil market risk due to a spillover effect (see, Liao et al., 2021). Otherwise, we assume that the asset acts as a safe haven for oil price returns. Second, we use the time-varying robust Granger causality test of Rossi and Wang (2019) to detect the exact time points of causality, if any. The later helps us to determine the safe haven behaviour of the

Table 6
Results from standard time-invariant Granger causality test.

	Panel A: Pre-Conflict announcement		Panel B: Post-Conflict announcement	
	H_0: Tail $\nRightarrow$ Oil	H_0: Oil $\nRightarrow$ Tail	H_0: Tail $\nRightarrow$ Oil	H_0: Oil $\nRightarrow$ Tail
Gold	2.391	2.661	6.772***	9.201***
PAX Gold	1.355	0.232	0.352	5.225**
UNUS SED LEO	0.013	0.208	0.585	0.233
Cryptojacks	0.502	0.000	0.142	0.779
ICOBID	0.974	0.001	0.340	0.693
Kuai Token	0.025	0.079	2.541	2.837*
CrevaCoin	0.239	0.023	0.836	0.583
Shivers	1.504	0.013	0.456	0.576
Bitcoin	3.154*	8.365***	0.000	0.459
Wrapped Bitcoin	4.248**	6.076**	0.001	0.134
IQeon	2.163	4.193**	0.057	2.153
CTRI	0.591	1.278	3.550*	0.085

Note: The table shows the chi-square statistic, χ^2, of constant parameter Granger causality test where the lag length is selected based on BIC. "Tail" denotes the tail risk measure of potential safe haven assets, gold and cryptocurrencies, while "Oil" denotes the oil price returns. $H_0: Tail \nRightarrow Oil$ ($\nRightarrow$ means "does not Granger-cause"). *, **,*** denote statistical significance at the 10%, 5% and 1% level, respectively.

Table 7
Results from time-varying parameter Granger causality tests.

	ExpW	MeanW	Nyblom	SupLR
Panel A: Pre-Conflict announcement				
Gold	314.692***	59.804***	3.127**	640.794***
PAX Gold	40.604***	11.831**	0.531	90.737***
UNUS SED LEO	13.247***	17.568***	1.430	37.771***
Cryptojacks	7.839***	7.046	1.350	22.937***
ICOBID	14.151***	7.419*	0.632	35.948***
Kuai Token	5.084**	3.948	0.418	20.888***
CrevaCoin	12.306***	15.064***	1.501	33.202***
Shivers	8.199***	7.495*	0.494	23.906***
Bitcoin	294.022***	121.755***	3.250**	598.909***
Wrapped Bitcoin	248.880***	128.091***	1.898	509.967***
IQeon	103.444***	83.653***	1.173	218.864***
CTRI	592.254***	180.879***	1.895	1196.715***
Panel B: Post-Conflict announcement				
Gold	67.364***	62.673***	15.879***	143.413***
PAX Gold	42.437***	28.910***	0.637	94.527***
UNUS SED LEO	25.419***	19.713***	0.571	57.866***
Cryptojacks	48.758***	35.832***	0.859	106.064***
ICOBID	69.159***	42.253***	0.552	147.903***
Kuai Token	3.643	4.310	0.809	13.550*
CrevaCoin	60.383***	40.507***	0.738	130.407***
Shivers	59.981***	40.170***	0.598	129.581***
Bitcoin	46.677***	32.706***	2.656*	101.908***
Wrapped Bitcoin	47.798***	33.327***	2.895**	104.041***
IQeon	43.459***	58.714***	0.794	94.357***
CTRI	32.886***	24.751***	0.878	75.266***

Note: Entries correspond to the exponential Wald (ExpW), the mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR) test statistics from time-varying robust Granger causality test of Rossi and Wang (2019). The null hypothesis is that oil price returns do not Granger cause the tail risk for a given potential safe haven asset. We assume heteroskedastic and serially correlated idiosyncratic shocks. ***, **, and * denote 1%, 5%, and 10% statistical significance levels, respectively.

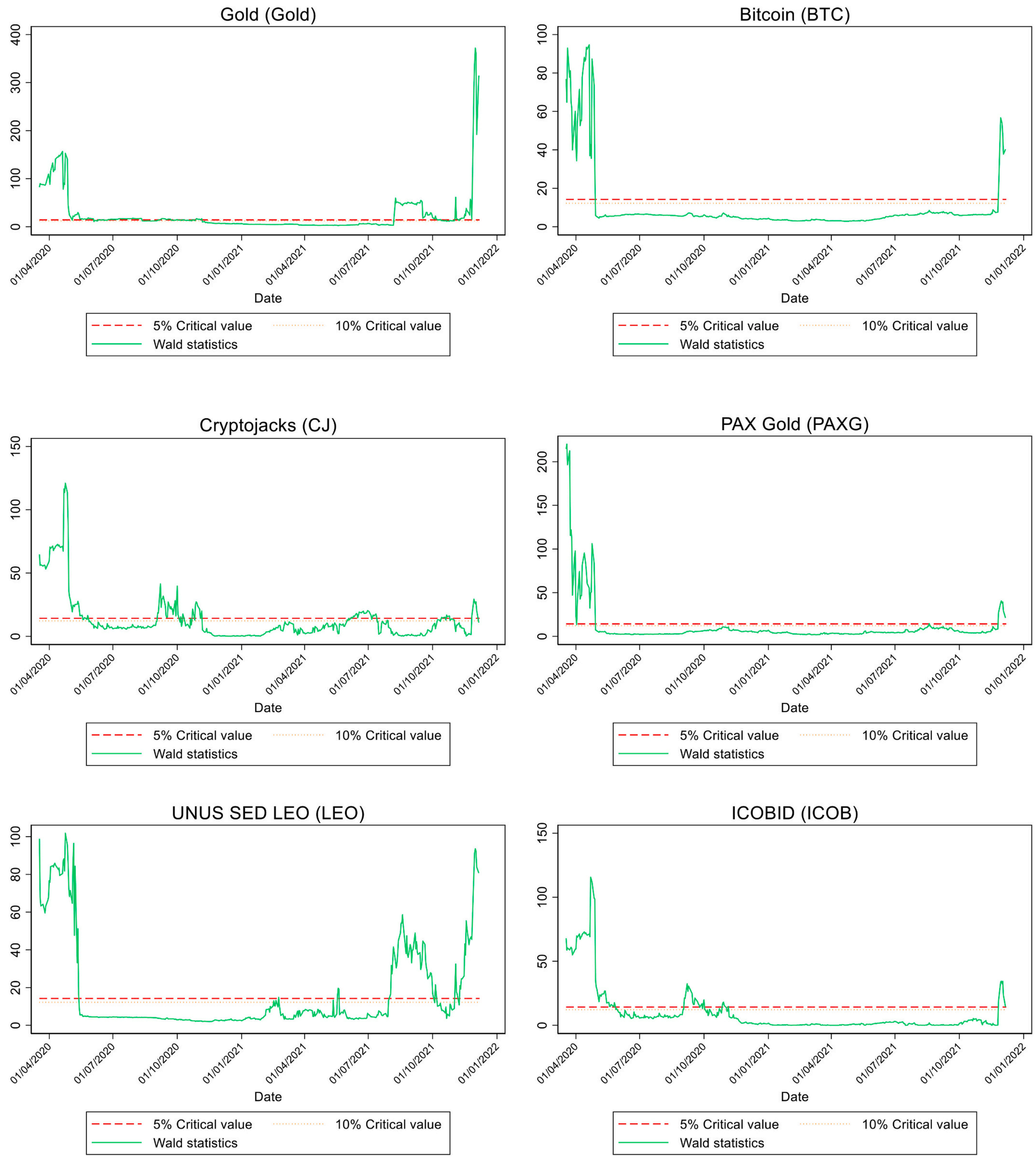

Fig. 2. Time-varying Wald test statistics: pre-conflict announcement.

assets for oil market at different stages of the 2022 Russia–Ukraine conflict, as well, as the COVID-19 pandemic. For both Granger causality methods, the null hypothesis of non-causality is specified against the alternative hypothesis of causality. The optimal lag length is determined by the BIC.

Table 6 presents the results from the standard time-invariant Granger causality test. In Panel A of Table 6, it can be seen that there exists a bi-directional causality between oil and two crypto assets, i.e., Bitcoin and Wrapped Bitcoin (WBTC), and a unidirectional causality from oil returns to IQeon. This implies that neither of the three assets can serve as a safe haven for oil in the pre-conflict period as those are exposed to risk spillover from the oil market. Intriguingly, neither of these three assets show evidence of causality during the 2022 Russia–Ukraine conflict, see Panel B in Table 6. This implies that all three assets become safe havens for oil market after the onset of the conflict. However, gold is the only asset that shows evidence of bidirectional causality with oil returns during the conflict times based on 1% level of significance. This finding suggests that gold may be exposed to oil price risks and its integration

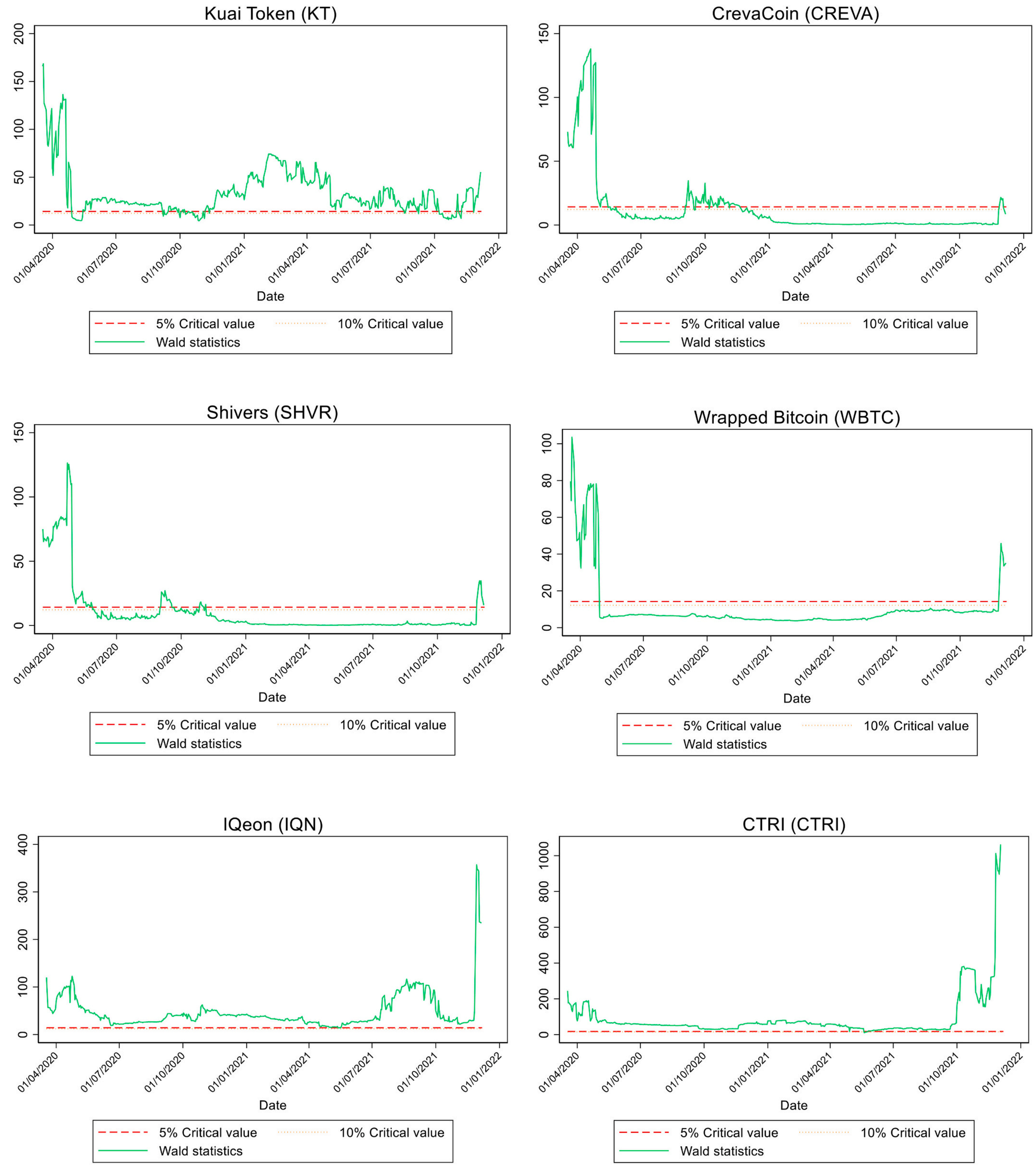

Fig. 2. (*continued*).

within an investment portfolio may increase the unsystematic risks, especially, in period of extreme energy market uncertainty. Besides, there exists a unidirectional causality from oil returns to PAX Gold (PAXG) and Kuai Token (KT), see Panel B in Table 6, which suggests that neither of the two assets can act as a safe haven for oil market in the conflict times. Overall, we conclude that some assets may act as safe haven for oil at the early stages of the COVID-19 pandemic, but the 2022 Russia–Ukraine conflict brought additional uncertainty in energy markets which has reflect on the safe haven properties of the crypto-currencies and gold.

In sum, the above evidence suggests that the safe haven properties vary over time and, therefore, this requires more careful estimation accounting for time variability. Therefore, we next explore the causal relationship relying on a more powerful Granger causality test that is robust to parameter instability.

Table 7 presents the results from the time-varying robust Granger causality method of Rossi and Wang (2019). The results are split into two panels: pre- and post-conflict announcement periods. The below discussion focuses on the causality results from oil price returns to the potential safe haven asset.[3] In contrast to the above results from the time-invariant Granger causality test, TVP-GC determines that all assets have periods of not acting as safe haven for oil market. This finding is based on the ExpW, MeanW, SupLR statistics at 10% level of significance and is valid regardless the estimation period. However, the results from the Nyblom statistics provide rather mixed evidence, indicating that gold and Bitcoin are the only assets that do not persistently serve as safe haven for oil in the pre-conflict period, considering 10% level of significance, whereas all other assets do. Surprisingly, this tendency remains unchanged and neither gold or Bitcoin can act as persistent safe haven for oil market after the outbreak of the military conflict. In addition, Wrapped Bitcoin also loses its safe haven properties during the conflict period with Nyblom coefficient of 2.895 being significant at 5% level. Nonetheless, the results from Table 7 show that there is no risk spillover from oil market to CTRI index, which represents the whole crypto market, suggesting that investment in portfolio of cryptocurrencies can offset oil risk in period of market downturn. This finding adds to study of Corbet et al. (2020) who are one of the first to investigate the safe haven properties of altcoins.

5.4. *Does the timing matter?*

In this section, we explore the exact time period when an asset has acted as a safe haven for oil price returns. Investigating this is quite important for policy makers and investors as not only to identify the persistence of an asset to serve as a safe haven but also to determine if the asset has served as a safe haven at the early stages of an event, for example, immediately after the outbreak of the 2022 Russia–Ukraine conflict, or the safe haven property occurs after a delay. To identify the exact periods when gold and cryptocurrencies act as safe haven for oil market, we utilize the results from TVP-GC tests of Rossi and Wang (2019).

Fig. 2 presents the TVP-GC results from oil returns to the potential safe haven assets in the pre-conflict announcement period. Interesting for this period is that it overlaps with the early stages of the COVID-19 pandemic and, in particular, the extraordinary event in April 2020 where West Texas Intermediate (WTI) oil future prices became negative. Fig. 2 shows that none but one of the assets, i.e., PAX Gold, serves as a safe haven for oil returns at the first quadrimester of 2020. Although PAX Gold shows only fugitive safe haven property, its timing coincides with the period of extreme oil market volatility where oil prices exhibit negative values. Therefore, we conclude that the commonly neglected altcoins may perform safe haven property in periods of extreme energy uncertainly for which typical hedging assets, such as gold and nowadays Bitcoin, show a clear causal dependence on oil. This finding adds to the study of Corbet et al. (2020) who show that altcoins exhibit safe haven properties.

Overall, the highest persistence in safe haven behaviour can be noticed for Bitcoin, PAX Gold, and Wrapped Bitcoin, which act as safe haven after the first stage of the pandemic. The causality evidence from oil returns to gold is rather mixed, with Wald statistics oscillating near the 5% critical value almost till the end of 2020, and getting back to this nature after the third quarter of 2021. The CTRI index, representing the whole cryptocurrency market, display Wald statistics close but still larger than the critical values, suggesting uncertainty about the safe haven properties of cryptocurrency market, as a whole. Thus, oil risks may not be as well hedged from a large portfolio of cryptocurrencies as from a single or couple of crypto assets. Our findings determine that after the initial uncertainty in the financial and energy markets brought by the outbreak of the COVID-19 pandemic, both gold and, especially, Bitcoin, show safe haven characteristics for oil. Last but not least, the period near the outbreak of the conflict is signified with a large change in the safe haven property of many assets. In particular, only few altcoins, such as Cryptojacks, ICOBID, and CrevaCoin lose but then regain back their safe haven property for oil returns. But for all other assets oil returns are causally linked. At this instant, altcoins are found to be the safest of all haven for investors.

Fig. 3 presents the TVP-GC results from oil returns to the potential safe haven assets in the post-conflict announcement period. Among all assets, Kuai Token, CrevaCoin, CTRI index, and gold show no evidence of non-causality. As such, four of them cannot be classified as safe haven for oil market during the conflict period. In detail, investors may fail to diversify the energy and, in particular, oil market risks if they include gold or a large portfolio of cryptocurrencies in their portfolios. In contrast, a large cap cryptocurrency such as Bitcoin show a better safe haven properties than the above four assets, but still those properties are very temporal and not persistent in time. As can be seen in Fig. 3, PAX Gold and IQeon act as a safe haven for oil returns for the longest time among all assets in the conflict period. This finding provides further support to study of Corbet et al. (2020) that altcoins contain safe haven properties.

In sum, we conclude that the typical safe haven assets, such as gold, may fail to deliver safe haven properties for oil returns in times when digital assets can do. While Bitcoin serves as a safe haven for oil in the early stages of the COVID-19 pandemic, this property has almost been lost during the conflict times. Some altcoins may provide better safe haven property than the commonly used hedge assets, but investment in them should be done carefully managed.

6. Robustness check

To assess the persistence of safe haven property of our assets, we consider longer-horizon analysis. Past studies have identified that safe haven properties of assets very across time and investment horizon, for example, gold (Bredin et al., 2015). Hence, we extend the TVP-GC framework, as of Eq. (11), into a multi-horizon TVP-GC forecasting model with time-varying parameters to investigate the out-of-sample forecasting ability of oil returns on the tail risk measures of gold and cryptocurrencies. The following multi-horizon, y_{t+h}, is estimated:

$$y_{t+h} = \Theta_{1,t} y_{t-1} + \Theta_{2,t} y_{t-2} \ldots + \Theta_{p,t} y_{t-p} + \varepsilon_{t+h} \qquad (12)$$

where h determines the forecasting horizon. In our case, we consider the following three time horizons: 5, 22, 66 days. Respectively, those refer to 1 week ahead, 1 month ahead, and 1 quarter ahead forecasting predictability.

Tables 8-10 present the results for various forecasting horizons. The results show that the causality patterns remain similar at the different time structures regardless the estimation period. In spite of that, the largest divergency from the main results is noticed for horizon of 1 week at the post-conflict announcement period based on the Nyblom test, see Table 8. The Nyblom test in Table 8 fails to detect causality from oil price returns to the potential safe haven asset in the case of only Kuai Token, at 10% significance level, and UNUS SED LEO and CTRI index, at 1% significance level. Overall, the remaining results provide further support to our main findings, see Tables 9 and 10.[4]

[3] The results for the reverse causality are available in Table A.3 at the Appendix.

[4] The results for the reverse causality are available in Tables A.4-A.6 at the Appendix.

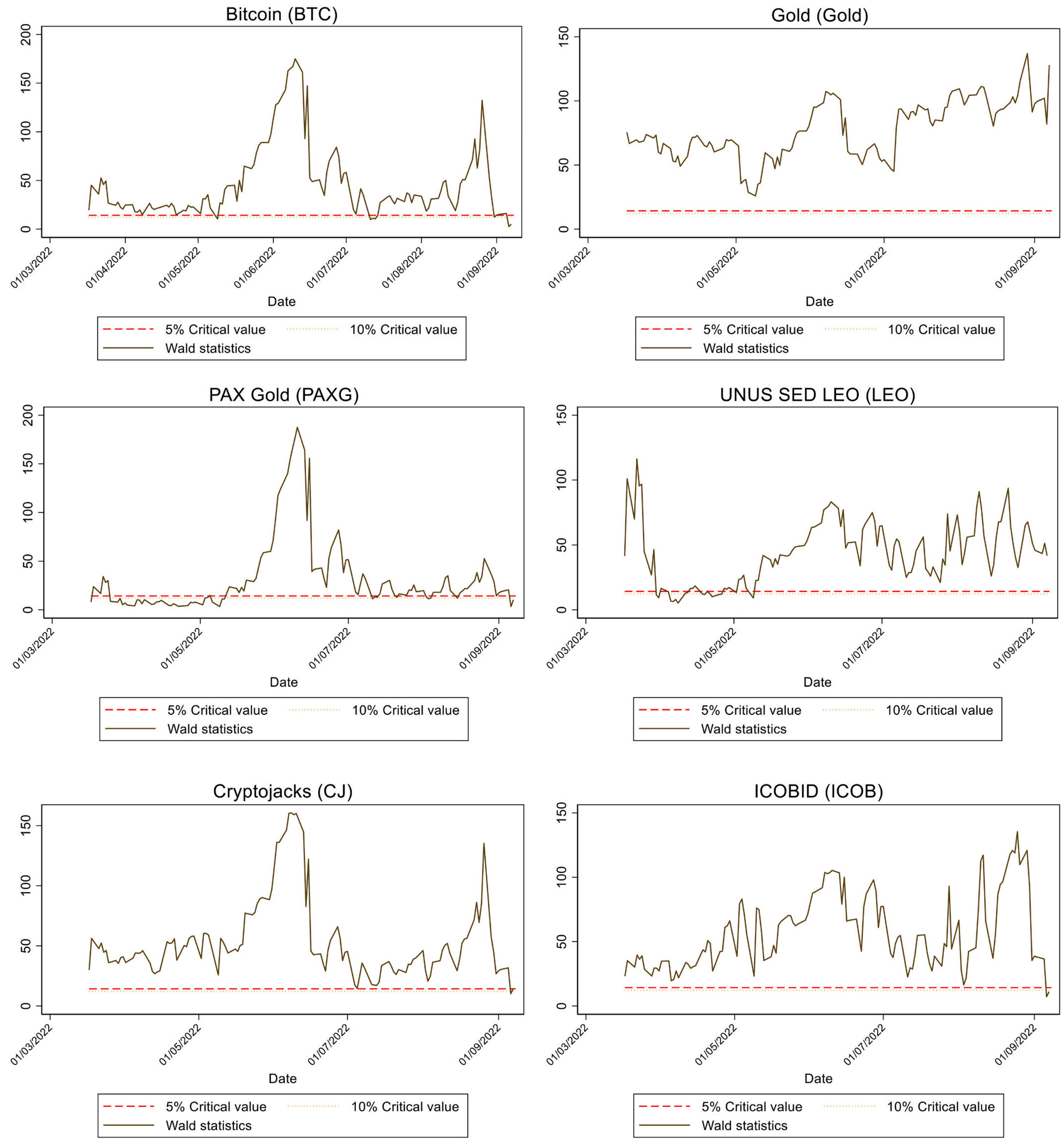

Fig. 3. Time-varying Wald test statistics: post-conflict announcement.

7. Conclusion

Our empirical results suggest that cryptocurrencies can act as safe haven for oil market during periods of market downturn. However, the safe haven property is not persistent over the full period, but it varies over time. We denote that Bitcoin often offer better safe haven properties than gold, especially, in the early stages of the COVID-19 period. Nonetheless, the altcoins can offer lengthier safe haven property than both gold and Bitcoin during the COVID-19 pandemic. To investigate, the safe haven characteristics of the whole crypto market, we created a new Cryptocurrency Tail Risk Index (CTRI) that captures the risk exposure of cryptocurrency market, as a whole. We found that cryptocurrency market, as a whole, can be safe haven in times when the large cap cryptocurrencies, such as Bitcoin, and traditional assets, such as gold, fail. This finding is valid regardless the estimation period, either it is COVID-19 or the 2022 Russia-Ukraine conflict. In other words, adding altcoins to an investment portfolio reduce the oil risk at least as good as gold and Bitcoin.

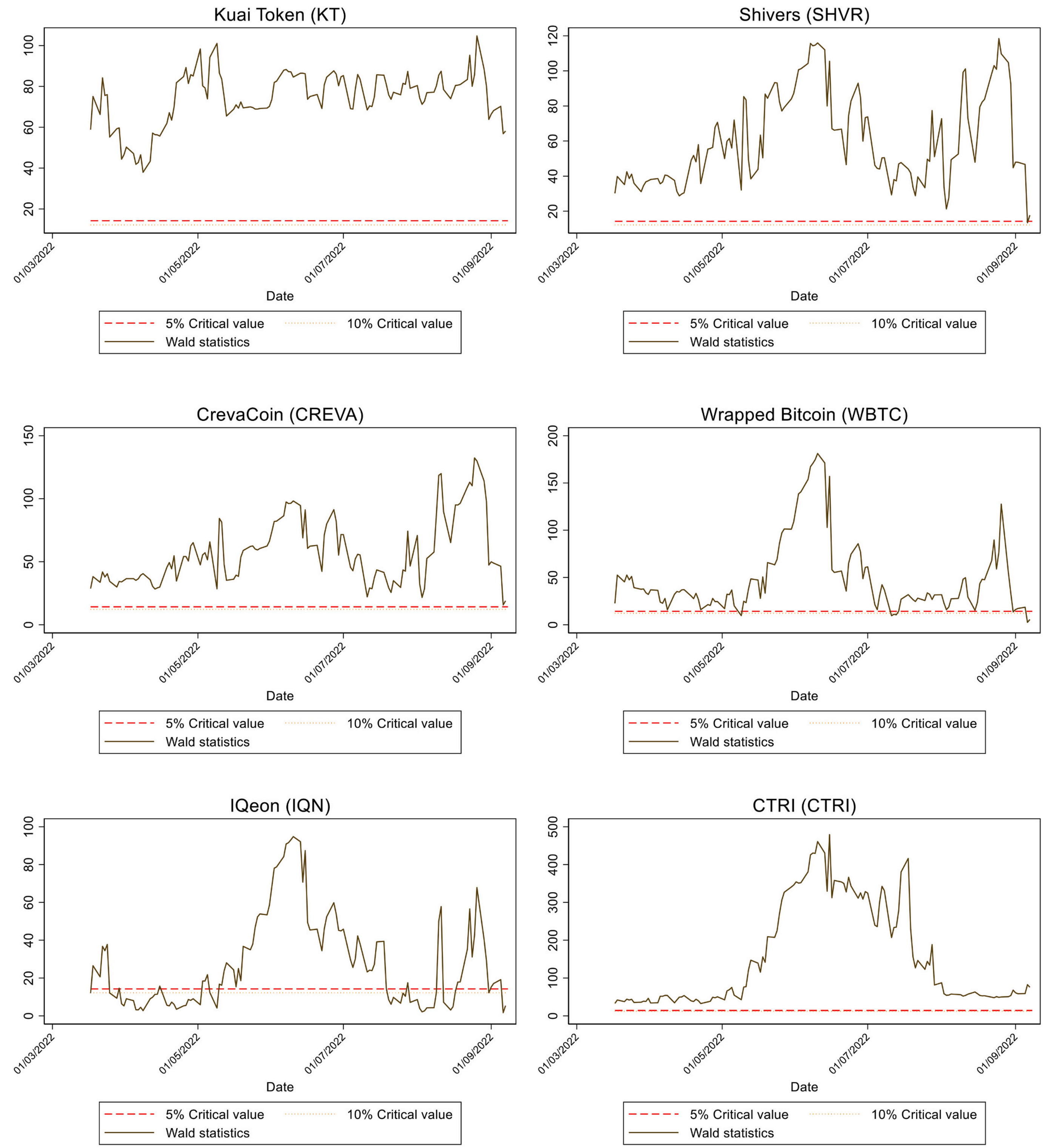

Fig. 3. (*continued*).

Table 8
Results from time-varying parameter Granger causality tests, 1 week ahead.

	ExpW	MeanW	Nyblom	SupLR
Panel A: Pre-Conflict announcement				
Gold	80.827***	48.892***	1.370	173.85***
PAX Gold	116.62***	39.995***	1.606	242.842***
UNUS SED LEO	47.708***	18.454***	1.905	105.018***
Cryptojacks	41.877***	11.499**	0.524	93.356***
ICOBID	61.445***	24.811***	0.957	132.491***
Kuai Token	24.476***	20.207***	1.640	56.689***
CrevaCoin	57.901***	19.936***	1.264	125.403***
Shivers	50.277***	21.161***	0.977	110.156***
Bitcoin	39.218***	12.731***	0.555	88.036***
Wrapped Bitcoin	21.025***	9.365**	0.586	51.440***
IQeon	95.446***	22.848***	3.681**	199.921***
CTRI	–	101.047***	2.413	1455.453***
Panel B: Post-Conflict announcement				
Gold	33.688***	23.862***	3404.012***	74.616***
PAX Gold	36.091***	20.227***	25.255***	80.893***
UNUS SED LEO	21.160***	22.308***	3.230**	48.792***
Cryptojacks	26.085***	22.117***	190.852***	61.715***
ICOBID	53.688***	27.669***	187.045***	116.977***
Kuai Token	42.291***	39.233***	1.333	92.988***
CrevaCoin	53.760***	29.500***	354.337***	117.121***
Shivers	49.139***	29.651***	403.072***	107.878***
Bitcoin	29.479***	26.532***	431.697***	67.173***
Wrapped Bitcoin	32.812***	32.028***	341.704***	73.121***
IQeon	28.062***	26.204***	9.792***	62.858***
CTRI	20.236***	18.348***	4.043**	48.998***

Note: Entries correspond to the exponential Wald (ExpW), the mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR) test statistics from time-varying robust Granger causality test of Rossi and Wang (2019). The null hypothesis is that oil price returns do not Granger cause the tail risk for a given potential safe haven asset. We assume heteroskedastic and serially correlated idiosyncratic shocks. ***, **, and * denote 1%, 5%, and 10% statistical significance levels, respectively. '–'denotes the case when the matrix fails invertibility condition.

Table 9
Results from time-varying parameter Granger causality tests, 1 month ahead.

	ExpW	MeanW	Nyblom	SupLR
Panel A: Pre-Conflict announcement				
Gold	133.133***	50.951***	3.711**	278.398***
PAX Gold	–	66.002***	1.710	1504.082***
UNUS SED LEO	23.075***	16.712***	2.541*	53.914***
Cryptojacks	35.818***	23.543***	1.013	81.654***
ICOBID	8.789***	5.002	0.586	26.455***
Kuai Token	11.245***	10.194**	6.592***	29.609***
CrevaCoin	85.367***	14.921***	0.656	182.864***
Shivers	10.137***	6.651	0.622	29.277***
Bitcoin	295.705***	106.414***	1.570	603.542***
Wrapped Bitcoin	464.919***	109.415***	1.350	940.961***
IQeon	130.044***	51.739***	0.557	271.864***
CTRI	215.369***	107.274***	1.675	442.867***
Panel B: Post-Conflict announcement				
Gold	–	–	–	–
PAX Gold	34.860***	35.503***	1.727	78.782***
UNUS SED LEO	5.388**	6.244	1.795	18.607***
Cryptojacks	34.801***	21.942***	1.229	77.710***
ICOBID	48.985***	19.041***	1.043	107.305***
Kuai Token	26.011***	31.710***	1.311	60.677***
CrevaCoin	110.125***	20.322***	1.697	229.612***
Shivers	60.057***	21.653***	1.401	129.436***
Bitcoin	24.436***	18.264***	1.199	57.886***
Wrapped Bitcoin	25.373***	22.396***	1.185	57.365***
IQeon	3.304	1.835	0.785	13.651*
CTRI	32.890***	49.507***	0.843	73.258***

Note: Entries correspond to the exponential Wald (ExpW), the mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR) test statistics from time-varying robust Granger causality test of Rossi and Wang (2019). The null hypothesis is that oil price returns do not Granger cause the tail risk for a given potential safe haven asset. We assume heteroskedastic and serially correlated idiosyncratic shocks. ***, **, and * denote 1%, 5%, and 10% statistical significance levels, respectively. '–'denotes the case when the matrix fails invertibility condition.

Our empirical results rely on big data consisting of 1066 active and continuously traded cryptocurrencies. Such large dataset provides us with a handful tool to explore the safe haven properties of not only the large cap digital assets but also on their small cap counterparts, i.e., altcoins. Thus, we provide a ranking with the top 10 safest cryptocurrency assets over the span of the full sample period. This finding is crucial for investors and policy makers in their attempt in searching for safe havens against oil market risks. In this circumstance, investors may look for best strategic response by exploiting as much dynamics from the data as possible, especially heterogeneity in tail risks and its exceedances. Our paper contributes to the current knowledge on the tail behaviour of cryptocurrencies, which is vital for investors, portfolio managers, and financial advisors targeting lower risks in time of market downswings, and for policymakers trying to cushion adverse impacts of energy market risks on the economy.

Several policy implications can be derived from our results contributing to the broader knowledge of investors and policymakers on safe haven assets. First, our study determines that among cryptocurrencies not only Bitcoin but also altcoins exhibit safe haven properties against adverse oil price movements. Therefore, investors can consider including altcoins in their portfolio baskets in order to minimize the non-systematic risk that comes from energy markets, especially, in times of a health pandemic and military conflict. Second, policymakers can implement reforms for a sustainable financial system that stimulate investment in cryptocurrencies. Our findings determine that gold does not act as a safe haven for oil market in a period of high economic uncertainty, in particular, during the first stage of the COVID-19 pandemic and the onset of the 2022 Russia–Ukraine conflict. However, the safe haven properties of gold are exposed when the intensity of the COVID-19 pandemic slows down. Hence, policymakers need careful assessment of the role, and scope, that gold plays in country's financial system in attempt for creating stable financial system resistant to high economic uncertainty. Digital assets, such as cryptocurrencies, can contribute in creating such organic financial environment in a country. Overall, both investors and policymakers need not negligee the diversification properties of cryptocurrency assets, especially, in times when global economic climate is triggered by high uncertainty.

Our paper suggests several avenues for future research. First, we focus on the energy market, as it has experienced large fluctuations in the COVID-19 pandemic and the subsequent Russia–Ukraine conflict, however, a future study can utilize our top 10 safest digital assets list to explore the safe haven ability of the listed cryptocurrencies for adverse price movements in stock markets, for example, in countries at various stage of development. Second, a further study can explore the safe haven properties of cryptocurrencies for a broader set of commodities, for example, agricultural commodities, whose terms of trade have been significantly affected by the outbreak of the 2022 Russia–Ukraine conflict, resulting in high risks and price uncertainty. Finally, it would also be interesting to investigate the safe haven characteristics of the cryptocurrency assets and gold in the later times of the 2022 Russia–Ukraine conflict by applying realized measures for tail risk forecasting.

Inclusion and diversity

The author list of this paper includes contributors from the location where the research was conducted who participated in the data collection, design, analysis, and/or interpretation of the work.

Table 10
Results from time-varying parameter Granger causality tests, 1 quarter ahead.

	ExpW	MeanW	Nyblom	SupLR
Panel A: Pre-Conflict announcement				
Gold	426.795***	21.469***	0.559	865.553***
PAX Gold	27.171***	26.326***	0.768	65.970***
UNUS SED LEO	19.709***	6.115	0.986	49.848***
Cryptojacks	19.027***	9.179**	0.615	47.537***
ICOBID	13.582***	8.371*	0.706	36.401***
Kuai Token	1.763	1.762	0.871	8.935
CrevaCoin	39.826***	14.130***	0.505	90.229***
Shivers	26.668***	12.053**	0.760	60.930***
Bitcoin	23.663***	24.318***	0.672	55.972***
Wrapped Bitcoin	21.796***	19.476***	0.783	53.115***
IQeon	145.354***	82.045***	0.453	302.671***
CTRI	205.773***	39.859***	1.622	423.506***
Panel B: Post-Conflict announcement				
Gold	64.047***	55.954***	1.141	135.200***
PAX Gold	102.464***	41.320***	1.915	213.504***
UNUS SED LEO	114.627***	23.675***	1.281	237.829***
Cryptojacks	76.586***	52.621***	3.616**	160.627***
ICOBID	23.928***	7.636*	7.636	55.505***
Kuai Token	25.853***	10.627**	1.639	60.219***
CrevaCoin	52.477***	17.472***	1.158	113.529***
Shivers	35.382***	20.119***	1.430	79.325***
Bitcoin	38.850***	25.576***	4.257***	86.275***
Wrapped Bitcoin	38.216***	31.429***	5.265***	84.315***
IQeon	173.836***	29.209***	0.976	356.247***
CTRI	33.418***	24.756***	2.101	74.497***

Note: Entries correspond to the exponential Wald (ExpW), the mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR) test statistics from time-varying robust Granger causality test of Rossi and Wang (2019). The null hypothesis is that oil price returns do not Granger cause the tail risk for a given potential safe haven asset. We assume heteroskedastic and serially correlated idiosyncratic shocks. ***, **, and * denote 1%, 5%, and 10% statistical significance levels, respectively.

CRediT authorship contribution statement

Martin Enilov: Conceptualization, Methodology, Software, Data curation, Investigation, Visualization, Writing – original draft. **Tapas Mishra:** Conceptualization, Methodology, Validation, Writing – review & editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.106690.

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