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Study on the dynamic relationship among economic policy uncertainty, bitcoin and energy price

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ABSTRACT

Bitcoin has garnered significant interest among investors, policymakers, practitioners, and market participants, with factors such as the Russia-Ukraine war and the constantly changing global uncertainties making crude oil prices unstable. The purpose of this paper is to examine the dynamic impact of Economic Policy Uncertainty (EPU) on the linkage between Bitcoin and crude oil prices using the TVP-VAR method, which represents a major starting point of this study. Through model analysis, it was found that, first, in the study examination, the linkage between EPU and the Bitcoin market is relatively high, implying the possibility of diversified relations. Second, the relationship between EPU and crude oil prices is quite significant in the short run, and the results also show that EPU's impact on crude oil prices is much more stable than on Bitcoin, a crucial factor to consider when assessing the impact of uncertainty on the interaction between Bitcoin and crude oil price markets. Third, there is evidence that Bitcoin's hedging properties for crude oil prices throughout the sample period are undeniable, having significant policy implications for policymakers and market participants. Therefore, in studying economic variables, EPU is an important influencing factor that policymakers and investors need to consider.

Contribution/ Originality: This study explored the dynamic relationship between economic policy uncertainty (EPU), Bitcoin, and crude oil prices using the TVP-VAR model. It contributes novel insights into how EPU impacts both cryptocurrency and energy markets, especially during major global events such as COVID-19 and the Russia–Ukraine war.

1. INTRODUCTION

Economic Policy Uncertainty (EPU) has become a prominent research topic in recent years. Initially, uncertainty was defined as an event whose outcome and the distribution of outcomes are unknown, and it was considered that uncertainty should be incorporated into asset returns. By using the dispersion of professional forecasters as a proxy for uncertainty, a strong correlation between asset market excess returns and uncertainty was verified (Anderson, Ghysels, & Juergens, 2009). In recent times, due to major events such as the US-China trade frictions, COVID-19, and the Russia-Ukraine conflict, EPU has attracted more widespread attention from all walks of life. In general, the concept of EPU commonly adopted was introduced by Baker, Bloom, and Davis (2016) as a proxy measure for uncertainty around economic policy. In everyday economic life, the effects of EPU on various economic indicators are profound, with its increasingly significant role in predicting financial asset returns being particularly prominent (Dai & Zhu, 2023; Ghani & Ghani, 2024; Ullah, Zhao, Amin, Syed, & Riaz, 2023; Yu, Gan, Zhou, & Dai, 2024; Zhang, Huang, & Wang, 2023).

After the global financial crisis of 2008, global investors' trust in financial markets gradually waned, which in turn led to speculation about decentralized forms of currency (Shaw, 2023; Zeng, Lu, & Ahmed, 2023). Bitcoin, invented by Nakamoto (2008) has attracted a large of attention as a decentralized cryptocurrency that operates without the need for a central bank or a single administrator, although the true identity of its creator remaining unknown (Alvarez, Argente, & Van Patten, 2023; Andolfatto, 2024; Fortin & Pimentel, 2024; Li, Hong, Wang, Xu, & Pan, 2022). Since then, on the one hand, Bitcoin has become increasingly popular among global investors and has become an essential part of the financial market, circulating in the world's major economies and being classified as a commodity in the United States, subject to the Commodity Exchange Act (Arkorful, Chen, Gu, & Liu, 2023). On the other hand, Bitcoin has proven to be one of the most profitable products in the past (Shah et al., 2023; Vlahavas, Karasavvas, & Vakali, 2024). Over time, technological advancements have helped Bitcoin become a globally recognized source of investment (Kirikkaleli & Sowah Jr, 2023; Sharif, Kocak, Khan, Uzuner, & Tiwari, 2023; Snene & Jeribi, 2024).

There is no doubt that the potential of Bitcoin as a safe-haven asset has been studied and validated in numerous studies (Jin & Tian, 2024; Riahi, Bennajma, Jahmane, & Hammami, 2024; Sharma & Karmakar, 2023; Wen, Tong, & Ren, 2022), especially it has acted as a safe harbor during periods of financial turmoil (Cheema, Faff, & Ryan, 2023; Narayan & Kumar, 2024; Syuhada, Suprijanto, & Hakim, 2022). Because Bitcoin operates independently from traditional assets and the global financial system (Wątorek, Kwapień, & Drożdż, 2023), it is considered that Bitcoin offers an alternative to the vulnerabilities of the financial system and financial institutions. Thus, during periods of economic stress, investors withdraw from traditional financial assets (Such as fixed income and stocks) and reallocate resources to Bitcoin, achieving incremental returns and profits (Hoque, Billah, Alam, & Tiwari, 2024) providing investors with a significant source of diversification (Tarchella, Khalfaoui, & Hammoudeh, 2024), it has the largest market capitalization among currencies and is considered a serious alternative to traditional currency systems and transactions. Bitcoin appears to be a form of money without gold and represents cash without any debt (Haynes, 2024). However, Bitcoin exhibits significant instability and bubbles in recent years; therefore, associated with Bitcoin is considered a speculative investment preference (Srivastava, Singh, & Rana, 2024).

Meanwhile, the consistency of Bitcoin with various volatilities and EPU depends on the investment time horizon (Hung, Huynh, & Nasir, 2024). For example, some researchers use multivariate quantile models to investigate the spillover effects of US EPU on Bitcoin, indicating that these impacts are uncorrelated, and they maintain that Bitcoin is a safe haven asset and a diversification tool against EPU shocks (He, Li, Wang, & Shah, 2024). The increasing acceptance of Bitcoin as a medium of investment stems from studies that refute early assessments, indicating that over time, Bitcoin has begun to adhere to the efficient market hypothesis (Yi, Yang, Jeong, Sohn, & Ahn, 2023). As for the country market, it has been observed that EPU negatively affects the dynamic conditional relationship between Bitcoin prices and US market returns (Aryan, Soleimani, & Shojaee, 2024; Mokni, Ajmi, Bouri, & Vo, 2020). While research on the Chinese market found a positive relationship between EPU and Bitcoin prices (Jia, Tiwari, Zhou, Farooq, & Fareed, 2023; Lau, Soliman, & Zhang, 2024). The variables affecting Bitcoin pricing are markedly different from those affecting standard investment asset classes (Wang et al., 2024; Wang, Ma, Bouri, & Zhong, 2022), including the number of Bitcoins traded daily, Google search volume, electricity prices, hash rate, and technology. Moreover, the volume of online searches indicates that EPU is a major driver of Bitcoin returns. Nonetheless, the relationship between EPU and Bitcoin prices has been explored in numerous studies (Będowska-Sójka, Górka, Hemmings, & Zaremba, 2024; He et al., 2024; Poddar, Misra, & Mishra, 2023; Singh, Bansal, & Bhardwaj, 2022).

On the other hand, crude oil, as a traditional fossil fuel and one of the most important sources of energy, has made significant contributions to global economic growth, but its use has also led to substantial carbon emissions. Therefore, the combustion of fossil fuels, while promoting economic expansion, has exacerbated environmental deterioration (Kartal, Kılıç Depren, Ayhan, & Depren, 2022; Wang & Azam, 2024) and spreads to EPU. In turn, EPU is likely to have a negative (positive) effect on the economy when increasing (decreasing), which may result in a decrease (increase) in the demand for and prices of oil (Nusair & Al-Khasawneh, 2023; Qin, Su, Hao, & Tao, 2020; Zhou, Huang, Gao, & Luo, 2024). However, crude oil prices are determined by the global market. EPU has a positive and significant impact on oil return volatility (Ma, Zhou, Cai, & Deng, 2019), but this effect is transient. Nonetheless, most studies find that the impact of EPU on crude oil price returns is negative (Husain, Sohag, & Wu, 2024; Liu, Shao, Li, Pan, & Qi, 2023; Zhang & Yan, 2020), especially during major international events such as the global financial crisis. Also some researchers found that the spillover effect of EPU on international crude oil market risk is nonlinear, asymmetric, and time-varying (Gong, You, Wang, & Ruan, 2024; He & Sun, 2024; Zhao & Zhu, 2023) with the impact of EPU on crude oil price varying among different countries (Hong, Zhang, & Zhang, 2024; Yao & Liu, 2023). EPU, whether stemming from monetary policy or potential fiscal decisions, suppresses the investment activities of various companies. This is due to the uncertainty felt by firms about future overall demand and rising financing costs (Pástor & Veronesi, 2013), leading to a decrease in investment levels and oil demand, ultimately driving the crude oil price down. Although studies on the relationship between EPU and crude oil (Husain et al., 2024; Liu et al., 2023; Liu, Su, Tao, & Lobonţ, 2024; Yuan, Li, Li, & Zhang, 2022) are numerous. Among these many studies, few have directly investigated the impact of EPU on the volatility of crude oil.

The primary purpose of this study is to explore the time-varying correlation between EPU and the prices of Bitcoin and oil. To our knowledge, the dynamic investigation of the interplay between EPU, Bitcoin, and crude oil is a relatively uncommon topic with limited research to date. Therefore, it not only aims to enrich our understanding of Bitcoin and related areas such as EPU but also seeks to expand the scope of related research. In the context of the global COVID-19 pandemic and localized conflicts such as the Russia-Ukraine war, the pattern of world economic development has become increasingly complex. Not only traditional financial markets and energy markets but also cryptocurrency markets have been significantly impacted. Specifically, for Bitcoin, which has existed for more than ten years, understanding its influencing factors has become a highly relevant and worthwhile issue to study. To be more specific, first, we systematically explore the dynamic correlation between EPU and both BTC and crude oil, which is somewhat a novel exploration. Second, our empirical analysis aims to follow a dynamic framework, which offers more advantages than traditional models such as VAR and GARCH. Economic variables are typically dynamic, reflecting immediate market changes in the short term and driven by macroeconomic fundamentals in the long term. Our research aims to reveal a dynamic relationship between EPU, BTC, and crude oil prices, exhibiting clear time-varying characteristics. Meanwhile, the impact of EPU within a certain range on BTC cannot be ignored in the study of Bitcoin, and likewise, the impact of EPU on crude oil prices should also be evident.

The main contributions of this paper are as follows: (1) It uses monthly data, which helps to explore more deeply the potential relationships among EPU, Bitcoin, and crude oil prices. To our knowledge, this is the first study to examine the correlation between EPU and the markets for energy and cryptocurrency. (2) Furthermore, it employs a dynamic perspective using the TVP-VAR model to study the time-varying correlation between EPU and the prices of Bitcoin and oil. By considering the time-varying nature of these relationships, this study enriches traditional time series data research. This approach allows for stability tests of the results and facilitates comparisons between different periods, providing a better understanding of the linkage mechanisms between the study variables. (3) This research also supports the work of Wang, Li, Ren, Bu, and Jawadi (2023), who found a dynamic correlation between EPU and oil. The contributions of this paper are evident. The research findings have high reference value for relevant policy formulation.

The remainder of this paper is organized as follows. Section 2 reviews the growing literature on the linkages between EPU, BTC, and the crude oil market. Section 3 describes the methodology used in the empirical analysis. Section 4 presents the data and empirical results, and Section 5 concludes the study.

2. LITERATURE REVIEW

2.1. EPU and BTC

To date, researchers have extensively examined Bitcoin from different perspectives. For instance, certain studies have investigated the market dynamics between Bitcoin and traditional financial assets and commodities, focusing on its hedging properties against these financial assets (Abdelmalek & Benlagha, 2023; Conlon, Corbet, & McGee, 2020; Tarchella et al., 2024; Urquhart & Zhang, 2019; Wang, Zhang, Yang, & Guo, 2021). Guesmi, Saadi, Abid, and Ftiti (2019) used various GARCH models to study Bitcoin's characteristics across different financial markets and revealed the interactions between Bitcoin and financial variables and its ability to hedge risks. Shahzad, Bouri, Roubaud, Kristoufek, and Lucey (2019) compared the hedging properties of Bitcoin and gold during extreme market conditions, determining that both assets function as weak hedges, with their effectiveness varying over time and across different markets. Their findings indicated that gold serves as a more effective hedge during stock market declines in developed economies, whereas Chinese investors may prefer Bitcoin to mitigate investment risk. Bouri, Shahzad, Roubaud, Kristoufek, and Lucey (2020), using the wavelet VaR method, concluded that Bitcoin offers superior diversification benefits compared to gold and commodities, positioning it as the most effective hedging asset, with gold following closely behind. Ji, Bouri, Lau, and Roubaud (2019) suggested that Bitcoin could serve as an alternative to gold, noting that rising gold prices tend to reduce demand for Bitcoin and weaken the linkage of Bitcoin market return spillovers between the two assets. However, Al-Khazali, Bouri, and Roubaud (2018) challenged the similarity between Bitcoin and gold, showing that gold's returns and volatility respond to macroeconomic news, whereas Bitcoin largely does not. Jia et al. (2023) found significant effects of Chinese stock market returns on Bitcoin, using data on the Chinese currency. They also observed the impact of gold prices on Bitcoin. During periods of high EPU, Bitcoin's return stability was higher, suggesting that during the sample period, Bitcoin could be considered a safe haven against EPU. More importantly, Bitcoin market investors consider liquidity volatility as liquidity risk, and when liquidity volatility is high, Bitcoin is no longer a safe haven against EPU. Zhang, Kong, Xu, and Qi (2024) further studies indicate that investors tend to ignore risks associated with liquidity volatility when the stock market is in fear or the cryptocurrency market is in greed. Moreover, during the COVID-19 pandemic, investors were more concerned about BTC's liquidity volatility, indicating a rise in risk aversion. He et al. (2024) examined the relationship between EPU and cryptocurrencies employing quantile regression and Granger causality analysis. It was found that EPU has little impact on the cryptocurrency market in the short term, while BTC can be used as a hedging tool in the short term, but this role diminishes over the long term. Recommendations include promoting a rational framework involving all parties, including governmental agencies, central banks, investors, stock exchanges, and financial institutions, to actively participate. This collaborative effort aims to reduce irrational volatility and increase the acceptability of cryptocurrencies. Essentially, this study highlights that cryptocurrencies have the potential to be used as EPU hedging instruments in the short term.

However, in studies on external factors leading to Bitcoin volatility, numerous researches have shown that EPU plays a significant role in Bitcoin volatility. Yen and Cheng (2021) found that China's EPU is negatively correlated with Bitcoin volatility, suggesting that Bitcoin can act as a hedging tool against EPU risk. Fang, Su, and Yin (2020) examined the impact of global EPU on Bitcoin volatility, but their conclusions differed. Lucey, Vigne, Yarovaya, and Wang (2022) constructed a weekly cryptocurrency uncertainty index (UCRY) to measure Bitcoin's uncertainty based on news reports. Although Demir, Gozgor, Lau, and Vigne (2018) predicted Bitcoin returns using the US daily EPU through quantile regression, they did not provide further evidence on the relationship between EPU and Bitcoin. Wang, Xie, Wen, and Zhao (2019) combined the US EPU index, stock market uncertainty index, and VIX to represent EPU and observed that the risk spillover effect of EPU to the Bitcoin market is not significant in most cases. Wang, Li, Shen, and Zhang (2020) highlighted the significance of US EPU on Bitcoin prices. Additionally, Colon, Kim, Kim, and Kim (2021) studied the impact of geopolitical and economic uncertainty on the cryptocurrency market, indicating that Bitcoin's ability to counteract EPU is weaker during bull markets. Panagiotidis, Stengos, and Vravosinos (2020), using different methods of sparse regression guided by principal components, also identified EPU as a key variable in Bitcoin prices. Mokni (2021), using symmetric and asymmetric quantile causality tests, found that EPU enhanced the predictability of Bitcoin returns under extreme market conditions in most countries. Paule-Vianez, Prado-Román, and Gómez-Martínez (2020) studied the impact of EPU on Bitcoin returns and volatility, showing that during more uncertain periods, both Bitcoin's returns and volatility increased, similar to gold, indicating that Bitcoin exhibits characteristics of an investment asset, especially as a safe asset. Foglia and Dai (2022) extended the literature on the spillover effects between EPU and the cryptocurrency uncertainty index, applying a time-varying parameter vector autoregression (TVP-VAR) model for empirical analysis. The results indicate that EPU has transnational spillover effects and can predict the cryptocurrency uncertainty index. Wu, Ho, and Wu (2022) based on the MIDAS framework, investigated the impact of global and national EPU on Bitcoin returns and long-term volatility. Similar results were found for global and national EPUs, where most national EPUs were positively correlated with Bitcoin returns but negatively correlated with Bitcoin's long-term volatility. China's EPU provided better explanatory power compared to global and other national EPUs. Moreover, Bitcoin's hedging capability and long-term volatility were more sensitive to Japan's EPU. Overall, our findings suggest that national uncertainty is an important criterion for guiding Bitcoin investment decisions.

2.2. EPU and Oil

As EPU can significantly affect market co-movement through macroeconomic fundamental channels (Arouxet, Bariviera, Pastor, & Vampa, 2024; Zhao & Wang, 2022), existing research has extended the impact of EPU to cross-asset correlations, with a portion of the literature examining the relationship between EPU and OIL. In the study by Gu, Zhu, and Yu (2021), the macroeconomic effects of the Geopolitical Risk (GPR) index and the EPU index on the crude oil market were compared and distinguished. Both uncertainty indices are closely related to the crude oil market. The results indicate that EPU shocks are quantitatively more significant, having a greater negative influence on the oil market and accounting for a larger portion of its fluctuations. In the study by Qin et al. (2020), wavelet analysis methods confirmed both positive and negative impacts of EPU on crude oil price, highlighting the influence of US EPU on the oil market. Conversely, crude oil prices have a positive impact on EPU, suggesting that a bullish oil market leads to an increase in EPU. According to Wang et al. (2022), economic policy decisions have a direct impact on economic activity, and EPU plays a significant role throughout business cycles. Antonakakis, Chatziantoniou, and Filis (2013) reported the sensitivity (negative effects) of dynamic stock market correlations, EPU, and implied volatility due to US economic recessions and overall oil demand shocks. The uncertainty generated by economic policy decisions, whether stemming from monetary policy or potential fiscal decisions, suppresses the investment activities of various companies (Byrne & Davis, 2004; Pástor & Veronesi, 2013) argue that this is because firms are uncertain about future overall demand and the pressure of rising financing costs, leading to a decrease in investment levels and crude oil demand, ultimately driving crude oil price down. In the study by Zhu, Chen, Ren, Xing, and Hau (2022), a wavelet-based multiscale causality-quantile regression method was used to uncover the complex relationships between crude oil, Chinese EPU, and stock returns. The study found a significant and strong predictive power of oil and EPU on industrial stock returns, particularly during extreme market conditions. Moreover, EPU's ability to explain industrial stock returns is stronger in the long term than in the short term.

EPU is likely to have a negative (positive) impact on the economy when increasing (decreasing). This could result in a decrease (increase) in both the demand for and the prices of crude oil. However, crude oil prices are determined by the global market. The study by Ma et al. (2019) found that EPU has a positive and significant impact on the volatility of crude oil returns, but this effect is transient, with a decay period of about one year. Notably, their results indicate that the US EPU index has the best predictive power for long-term crude oil return volatility, while the Chinese EPU index performed best in predictions over the past year. Cheng, Liu, Jiang, and Cao (2022) investigated the risk associations between various categories of China's EPU and global crude oil price across both time and frequency domains. The study found that China's EPU, in most cases, receives risk spillover from the global crude oil price. Yao and Liu (2023) employed the popular GARCH-MIDAS model to investigate the predictive performance of the World Uncertainty Index (WUI) in crude oil volatility. The study found that the model performs better in predicting EPU and the Geopolitical Risk Index (GPR). Through inclusion tests, the research provided strong evidence that the predictive content of WUI can incorporate EPU and GPR to predict oil volatility. Khan, Khan, Sharif, and Suleman (2023) discovered that global policy uncertainty leads to a negative correlation between gold prices and Islamic stock markets, a medium-term negative correlation between gold prices and crude oil prices during crises, and a positive correlation between crude oil prices and Islamic stock markets.

Furthermore, Zhang and Yan (2020) used the DCC-GARCH model to investigate the potential impact of EPU on crude oil prices. The study found that during the sample period, nearly all US EPU indices were negatively correlated with West Texas Intermediate (WTI) returns. Moreover, almost all EPU indices had a significant impact on WTI returns within the 1-6 month and 6–12-month frequency bands. However, in the 12–24-month frequency band, only monetary policy uncertainty, regulatory policy uncertainty, and national security policy uncertainty had a significant impact on WTI returns. Notably, during major international events like the global financial crisis, the impact of the US EPU index on WTI returns was particularly strong. In the study by Zhao and Zhu (2023), a GARCH-tDDC-Copula model was established to investigate the spillover effects of US EPU on the international crude oil market risk. Additionally, a median-CoVaR portfolio model was constructed to discuss the optimal portfolio strategies for crude oil-importing countries under different states of US EPU. Empirical results indicate that the spillover effects of US EPU on the international crude oil market risk are nonlinear, asymmetric, and time-varying. In the study by Liu et al. (2023), a joint EGARCH-MIDAS-ARJI model was used to address the challenges of mixed data sampling. The research found that crude oil price volatility is negatively correlated with EPU. This finding challenges the neoclassical economic perspective that policy intervention is the primary source of market volatility, as higher EPU values suggest that policymakers are implementing beneficial policy measures. Yuan et al. (2022) investigated the relationship between EPU, crude oil prices, and stock markets in the BRICS nations under different market conditions. The empirical results show that during the Brent crude oil market boom periods, EPU in China and India negatively affected crude oil price returns, while EPU in Russia and Brazil had a positive effect. Overall, EPU in the BRICS nations had an inverse effect on the stock market. The economic policies of China and Russia were found to be more susceptible to fluctuations in the crude oil and stock markets. Additionally, the stock markets in the BRICS nations were more sensitive to negative crude oil price returns, while the oil market was more influenced by positive stock returns.

2.3. Bitcoin and Oil

The relationship between Bitcoin and crude oil has been extensively studied. Gajardo, Kristjanpoller, and Minutolo (2018) noted that, compared to other currencies, Bitcoin has a broader multifractal spectrum with crude oil (specifically, West Texas Intermediate, WTI). Ghazani and Khosravi (2020) found cross-correlations between Bitcoin and crude oil (both WTI and Brent). Van Wijk (2013) reported a negative correlation between Bitcoin and crude oil price, finding that, in the long run, Bitcoin's value is significantly influenced by WTI crude oil price. According to Ciaian, Rajcaniova, and Kancs (2016), crude oil prices are considered a significant determinant of Bitcoin volatility. Huynh, Shahbaz, Nasir, and Ullah (2022) found that oscillations in US and European crude oil indices closely correlate with most cryptocurrency trends, where European crude oil prices are a source of shocks to cryptocurrencies, while the US crude oil index is a receiver. Meanwhile, Su, Qin, Tao, and Umar (2020) explored the causal relationships and impacts between Bitcoin and crude oil markets. Their analysis indicates that the impact of crude oil price on Bitcoin could be either positive or negative, suggesting that Bitcoin can act as an asset to avoid the risk of high crude oil price but also implying that the burst of Bitcoin bubbles weakens its hedging capability. Jin, Yu, Hu, and Shang (2019) examined price volatility in Bitcoin, gold, and crude oil, finding that spillover effects from gold and crude oil markets to the Bitcoin market are stronger than those from other markets. They also discovered a negative dynamic correlation between Bitcoin and crude oil markets. Selmi, Mensi, Hammoudeh, and Bouoiyour (2018) investigated the potential of using Bitcoin to hedge against crude oil price volatility and found that Bitcoin can serve as a hedging tool. However, understanding the nuances of crude oil price volatility is key to comprehending the nature of these price fluctuations.

Previous research has explored the relationship between Bitcoin and crude oil. According to Dutta, Das, Jana, and Vo (2020), Brent crude and West Texas Intermediate (WTI) crude oil prices fell to their lowest levels of less than $23 per barrel at the end of March 2020. The WTI crude oil price even turned negative on April 20, 2020 (Corbet, Goodell, & Günay, 2020). Devpura and Narayan (2020) reported an increase in the volatility of crude oil prices following the outbreak of COVID-19. Das, Le Roux, Jana, and Dutta (2020) found that Bitcoin's hedging capacity against crude oil price-related uncertainties was minimal, and the asset's potential hedging capacity depends on the level of uncertainty present in the market. Kaabia, Abid, Guesmi, and Sahut (2020) used a Bayesian VAR model and found a significant positive correlation between Bitcoin and all crude oil prices. Ozturk (2020) also examined the relationship between Bitcoin, crude oil, and gold, finding that the relationship value (measured by volatility) among these three variables was close to 70%. Okorie and Lin (2020) used the VAR MGARCH GJR-BEKK method and the Wald test to study the volatility relationship between crude oil and Bitcoin. The study revealed bidirectional relationships and unidirectional volatility between the crude oil and cryptocurrency markets.

Sharma, Shahbaz, Singh, Chopra, and Cifuentes-Faura (2023) utilized daily data from the United States from August 2016 to August 2021 for their empirical analysis. Employing Quantile-on-Quantile Regression (QQR) and Quantile Granger Causality methods, it was shown that the green economy or institutions' green financing is highly sensitive to economic shocks, fluctuations in crude oil prices, and broader changes in sustainability. The empirical results further revealed a negative correlation between sustainability and crude oil prices, as well as sustainability and the stock market; crude oil prices and the stock market are also sensitive to changes related to sustainability. Feng, Gao, Duan, and Urquhart (2023) investigated the impact of decomposed crude oil price shocks on Bitcoin through a quantile-based framework, exploring Bitcoin's potential role as an investment safe haven under various oil price volatilities. They found an asymmetric and unidirectional causal relationship between Bitcoin/gold and crude oil price shocks. This unidirectional causality is present only in demand and supply shocks of crude oil price, not in risk-specific shocks, and is more evident at median quantiles. Salisu, Ndako, and Vo (2023) discovered that higher crude oil prices tend to increase the cost of producing Bitcoin, thereby reducing its returns and subsequently its transactions and volatility. Considering crude oil prices, our proposed model outperforms the benchmark model (random walk model) in predicting Bitcoin realized volatility, regardless of crude oil price variables and forecast horizons. Naeem, Karim, Abrar, Yarovaya, and Shah (2023) found that, under normal and bullish market conditions, crude oil price returns are positively correlated with cryptocurrency returns in the first lag period; however, under all market conditions, there is a negative correlation between crude oil price returns and cryptocurrency returns. Moreover, the rising volatility of crude oil price demand shocks significantly affects cryptocurrency returns under bear market conditions, and crude oil price demand shocks are unlikely to move in the same direction as cryptocurrency returns.

3. DATA, VARIABLES, AND METHODOLOGY

3.1. Sample Data

Our study utilizes monthly data from March 2012 to December 2023 to investigate the dynamic relationship between EPU and the prices of Bitcoin and crude oil over the past decade. The EPU index data from the United States were obtained from https://www.policyuncertainty.com/, an index developed by Baker et al. (2016)[1] and widely applied in economic and financial research (Aftab, Haq, & Albaity, 2023; Hernandez, Hasan, & McIver, 2023; Naboka-Krell, 2024; Wu et al., 2022). Hence, considering factors such as dynamic relationships, our study chose to use monthly data. Since Bitcoin trades 24 hours a day, seven days a week, we filtered the data series to retain only common observations. As a result, we obtained 142 monthly observations for each series. Bitcoin price data was retrieved from CoinMarketCap (https://coinmarketcap.com/), a widely recognized platform that provides comprehensive and well-organized information on Bitcoin prices and related indicators, making it a popular resource in numerous academic studies Dobrynskaya (2024); Feng and Zhang (2023); Fieberg, Günther, Poddig, and Zaremba (2024); Liu et al. (2023) and Tsuyuguchi and Wang (2025). Furthermore, crude oil prices were sourced from Yahoo Finance (https://finance.yahoo.com/), a popular resource frequently employed in economic and financial research (Aljethi & K ılıçman, 2023; Divyashree et al., 2024; Ho, 2023; Pellattiero & Candelieri, 2024).

Figure 1 illustrates the overall trend of the EPU index during the sample period, which can be broadly divided into three phases: a downward trend from 2012 to 2014, reaching its lowest point around June 2014, followed by a fluctuating increase, peaking around 2020. The periods before the COVID-19 pandemic (May 22, 2014, to December 31, 2019) and during the COVID-19 pandemic (January 1, 2020, to March 21, 2023) are highlighted. It is observable that before the COVID-19 pandemic in 2020, significant periods of higher EPU were only evident in the latter half of 2015, while other periods remained relatively stable. However, during the COVID-19 pandemic in 2020, the EPU increased significantly overall due to heightened uncertainty and panic caused by COVID-19. Since the second half of 2020, the EPU has begun to decline relatively substantially, and by the middle of 2021, it has started to fluctuate and stabilize somewhat.

Figure 2 depicts the price trend of Bitcoin, showing a clear upward trend during the sample period, despite a significant pullback in 2018. Industry observers often cite regulatory developments in Asia and speculative behavior as the main drivers of this downturn, while academic research points to the impact related to the introduction of Bitcoin futures and an increase in EPU (Kalyvas, Papakyriakou, Sakkas, & Urquhart, 2020). A review of Bitcoin's trading price indicates that it was relatively stable before 2017. After experiencing a rapid increase in 2017, the price began to decline in early 2018 and continued to fall until early 2019. Subsequently, a new upward trend commenced. Bitcoin prices demonstrated an upward trajectory, particularly from October 2020 to March 2021. There was a sharp decline in May 2021, followed by a rebound, and after reaching an all-time high in November 2021, it underwent another correction phase until the end of 2022.

Figure 3 shows the trend in crude oil prices, presenting an interesting pattern during the sample period, characterized by a double-V trend. Throughout the period from 2012 to the first half of 2014, crude oil prices remained above $80 per barrel. In the second half of 2014, prices plummeted to $34 per barrel in early 2016, then started to rebound, reaching $74 per barrel in June 2018, followed by a significant pullback. The initial stages of the COVID-19 pandemic in April 2020 saw crude oil prices drop to their lowest at $18 per barrel, highlighting the sharp decline during the outbreak. Significant fluctuations occurred around March and April 2020. Crude oil prices showed a consistent upward trend, especially during the Russia-Ukraine conflict in early 2022, reaching a high of $105 per barrel.

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[1] The EPU Index website was developed by Baker et al. (2016). One global-level and 21 national-level EPU indices were used. There are 14 developed markets in the selected countries (Australia, Canada, France, Germany, Hong Kong, Ireland, Italy, Japan, the Netherlands, Singapore, Spain, Sweden, the United Kingdom, and the United States) and 7 emerging markets in the selected countries (Brazil, Chile, China, Greece, India, Korea, and Russia) (Wu et al., 2022).

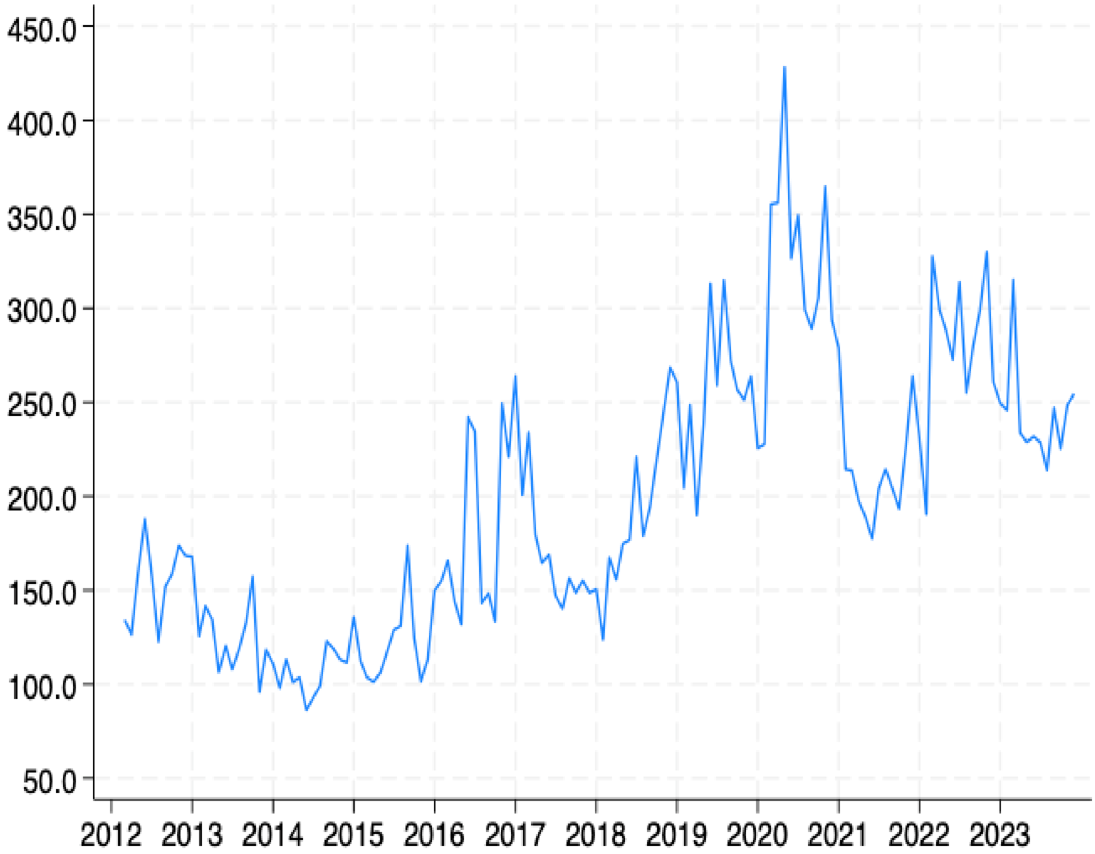

Figure 1. Trend of EPU.

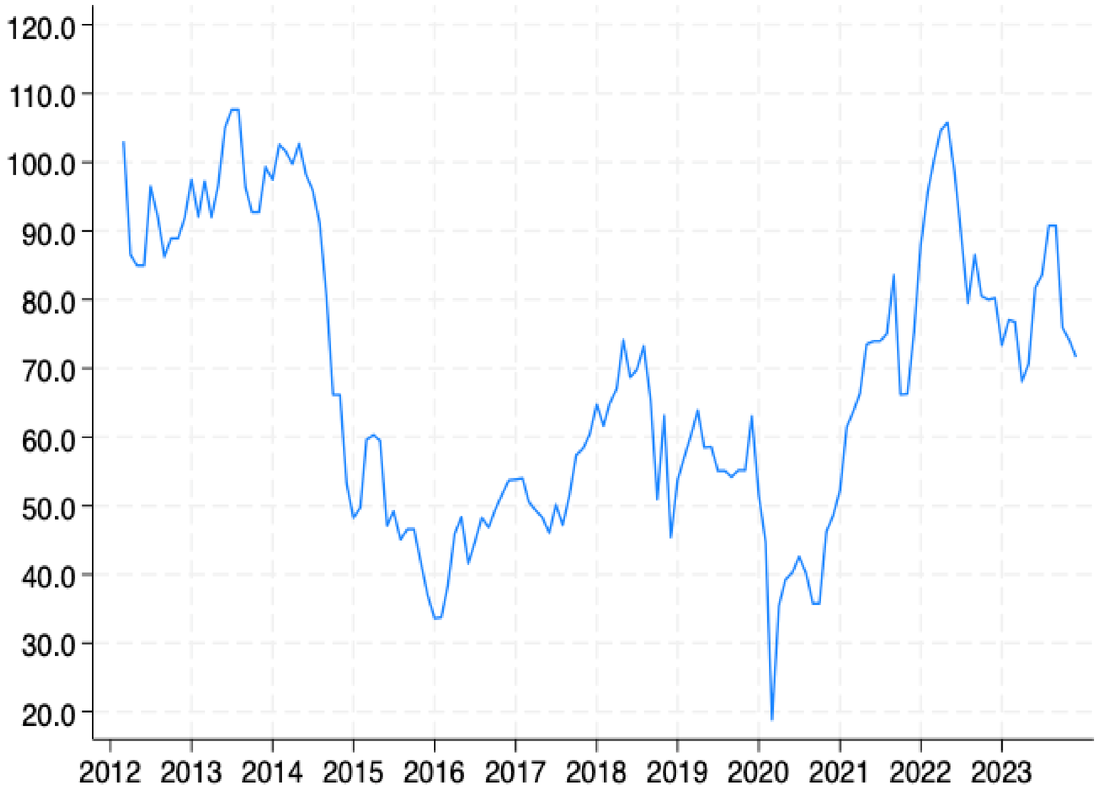

Figure 2. Trend of crude oil prices.

Figure 3. Trend of BTC prices.

In most empirical studies, it is necessary to first provide a priori knowledge about the statistical properties of the base series. Therefore, we follow this norm by revealing brief statistical information about the series. Table 1 presents the descriptive statistics and preliminary test results of the dataset. Looking at the range statistics, the maximum and minimum values of EPU are 428.153 and 86.283, respectively, with an average value of 197.407 and a standard deviation of 72.724. The maximum and minimum values of Bitcoin prices are 61,330.000 and 4.900, respectively, with an average value of 11,619.040. The substantial fluctuation range of Bitcoin prices is relatively narrow, with a standard deviation of 15,543.600. In comparison, the maximum and minimum values of crude oil prices are 107.650 and 18.840, respectively, with an average value of 68.198 and a standard deviation of 20.977, placing it in the middle range among these variables. Regarding their volatility, we observe that the standard deviation of EPU is 72.724, that of Bitcoin is 15,543.600, and the crude oil market exhibits the least volatility. This implies that the volatility of uncertainty plays a significant role in the direction and behavior of investors and other market participants in terms of risk hedging. In all cases, the Jarque-Bera test statistic is significant, rejecting the null hypothesis of normality for all series, further confirming that each variable's return series does not conform to a normal distribution, making them suitable for further study. Each variable's series shows negative skewness and kurtosis greater than 3, indicating that their distributions are leptokurtic. Considering the report of skewness and kurtosis statistics, it is not surprising that the Jarque-Bera test rejects the null hypothesis of normal distribution for all series. Although all return series' skewness values fluctuate between positive and negative, their kurtosis estimates exceed the standard threshold, indicating the presence of extreme volatility in these asset markets.

Table 1. Descriptive statistics of variables.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
EPU	197.407	188.540	428.153	86.283	72.724	0.547	2.606	8.003**
BTC	11619.040	4542.600	61330.000	4.900	15543.600	1.456	4.131	57.761***
Oil	68.198	65.730	107.650	18.840	20.977	0.171	1.941	7.322**

Note: *** p<0.01, ** p<0.05 represent 1%, 5% significant level.

3.2. Mathematical Components Formatting

The TVP-VAR model, initially introduced by Primiceri (2005), serves as an extension of the traditional VAR model. Unlike conventional VAR models, the TVP-VAR model features coefficients and a variance-covariance matrix that change over time, making it well-suited for capturing nonlinear and time-varying relationships between economic assets. This approach has become popular among scholars for investigating the relationships between various financial assets (Huang, Duan, & Urquhart, 2023; Jiang, Li, Lu, Wang, & Wei, 2022; Liu, Huang, & Lu, 2024; Wen, Cao, Liu, & Wang, 2021; Zhao, Wen, & Wang, 2020). The structure of the TVP-VAR model is outlined as follows.

The VAR (Vector Autoregressive) model can be expressed as follows.

$$Ay_t = F_1 y_{t-1} + \ldots + F_s y_{t-s} + \mu_t, t = s+1, \ldots, n \quad (1)$$

In Equation 1, y_t represents a $k\times1$ dimensional vector consisting of observed variables, while A、 $F_1 \ldots F_s$ denote $k\times k$ coefficient matrices, the term μ_t represents a $k\times1$ dimensional disturbance term, which follows a normal distribution $N(0, W)$ in Equation 2:

$$W = \begin{bmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_k \end{bmatrix} \quad (2)$$

When using recursive methods to identify contemporaneous structural shocks, it is required that a lower triangular matrix A in Equation 3.

$$A = \begin{bmatrix} 0 & 0 & \cdots & 0 \\ \alpha_{21} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{k1} & \cdots & \alpha_{k,k-1} & 1 \end{bmatrix} \quad (3)$$

Equation 1 can be expressed as Equation 4:

$$y_t = B_1 y_{t-1} + \ldots + B_s y_{t-s} + A^{-1} \sum \varepsilon_t, \varepsilon_t \sim N(0, I_k) \quad (4)$$

In Equation 5, $B_i = A^{-1} F_i, i = 1 \ldots s$, and

$$\sum = \begin{bmatrix} \sigma_1 & 0 & \ldots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \ldots & 0 & \sigma_k \end{bmatrix} \quad (5)$$

By stacking all the row vectors of B_i, we form a new matrix $\beta(k^2 s \times 1)$, defined as $X_t = I_k \otimes (y'_{t-1}, \ldots, y'_{t-s})$, where $\otimes$ represents the Kronecker product. This allows us to transfer Equation 4 into:

$$y_t = X_t \beta + A^{-1} \sum \varepsilon_t, X_t = I_k \otimes (y'_{t-1}, \ldots, y'_{t-s}) \quad (6)$$

All parameters in Equation 6 are assumed to be constants. However, if we relax this constraint, the equation can be extended to allow time-varying parameters as follows:

$$y_t = X_t \beta_t + A_t^{-1} \sum t \varepsilon_t, t = s+1, \ldots, n \quad (7)$$

Equation 7 represents the form of a time-varying parameter VAR (TVP-VAR), where the coefficients β_t, A_t, and $\sum_t$ vary over time. The TVP-VAR model is utilized to investigate the effects of the EPU on BTC and Crude oil prices. The observed dependent variable vector y_t is a $k \times 1$ order, where $y_t = [EPU, BTC, OIL]$ represents the variables in Bitcoin price analysis. In line with the methodology proposed by Primiceri (2005), the vector of stacked elements in the lower triangular matrix A_t is denoted by a subscript "0". Assuming that $h_t = (h_{1t}, \ldots h_{kt})', h_{jt} = ln\, \sigma_{jt}^2, j = 1, \ldots, k, t = s+1, \ldots, n$ evolve according to a random walk process, reflecting their time-varying nature in Equation 7.

$$\begin{aligned} \beta_{t+1} &= \beta_t + \mu_{\beta t} \\ \alpha_{t+1} &= \alpha_t + \mu_{\alpha t} \\ h_{t+1} &= h_t + \mu_{ht} \end{aligned}, \quad \begin{pmatrix} \varepsilon_t \\ \mu_{\beta t} \\ \mu_{\alpha t} \\ \mu_{ht} \end{pmatrix} \sim N\left(0, \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \sum\beta & 0 & 0 \\ 0 & 0 & \sum\alpha & 0 \\ 0 & 0 & 0 & \sum h \end{pmatrix}\right) \quad (8)$$

$$\beta_{s+1} \sim N(\mu_{\beta 0}, \textstyle\sum \beta 0), \alpha_{s+1} \sim N(\mu_{\alpha 0}, \textstyle\sum \alpha 0), h_{s+1} \sim N(\mu_{h0}, \textstyle\sum h0)$$

Furthermore, assuming that the shocks to the time-varying parameters are uncorrelated and that matrices $\sum\beta$, $\sum\alpha$, and $\sum h$ are diagonal, Equation 8, postulates that all parameters evolve according to a random walk process. As noted by Primiceri (2005), this assumption allows for the possibility of both temporary and permanent changes in the parameters, thereby capturing gradual or sudden shifts in the underlying dynamics. For the estimation of this model, a Markov Chain Monte Carlo (MCMC) method is employed, consistent with the approach suggested by Nakajima (2011). This estimation technique has been widely applied in numerous other studies (Huang et al., 2023; Jiang et al., 2022; Qin, Wu, Ma, Albu, & Umar, 2023; Su, Yang, Qin, & Lobonţ, 2023; Wen et al., 2022).

4. RESULTS

4.1. Stationarity Test

The stationarity of time series data significantly impacts the outcomes of empirical analysis. For non-stationary time series, random patterns can change over time, making it challenging to capture the overall randomness of the series based solely on existing data. Therefore, testing for stationarity is crucial before performing any empirical analysis. Table 2 shows the results of the unit root test conducted on the variables in this study. Both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests rejected the null hypothesis of a unit root, as all the calculated test statistics were lower than the critical values. These results are further supported by two unit root tests based on GARCH models, specifically those by Perron (2006) and Lee and Strazicich (2003). As a result, we can conclude that all regression series are stationary and can be confidently used for empirical analysis.

Table 2. Stability test of variables.

Variable	ADF	PP	1% critical value	5% critical value	10% critical value	Stationarity
EPU	-4.780	-4.654	-4.025	-3.442	-3.146	Stationary
BTC	-10.205	-9.018	-4.025	-3.442	-3.146	Stationary
Oil	-13.703	-10.674	-4.025	-3.442	-3.146	Stationary

4.2. Analysis of Parameter Estimation Results

In a Vector Autoregression (VAR) model with stable parameters, each parameter is associated with a single estimated value. However, in a TVP-VAR model, the estimate of each parameter evolves over time, resulting in time-varying parameters represented in charts as fluctuating trend curves. We employ a TVP-VAR model to analyze the impulse responses of Economic Policy Uncertainty (EPU) on Bitcoin (BTC) and crude oil price markets, as well as across different lag periods. The objective is to determine the dynamic relationship between EPU and the markets for Bitcoin and crude oil. We use the Akaike Information Criterion (AIC), among other criteria, to select a 1-lag TVP-VAR model. Subsequently, we employ the Markov Chain Monte Carlo (MCMC) method for 10,000 iterations to obtain effective samples. Figure 4 displays the sample autocorrelation function, the path of sample values, and the density function of the posterior distribution. After discarding the burn-in period samples, the sample autocorrelation steadily decreases, and the path of sample values stabilizes. This indicates that the sampling method has generated relatively uncorrelated samples to some extent.

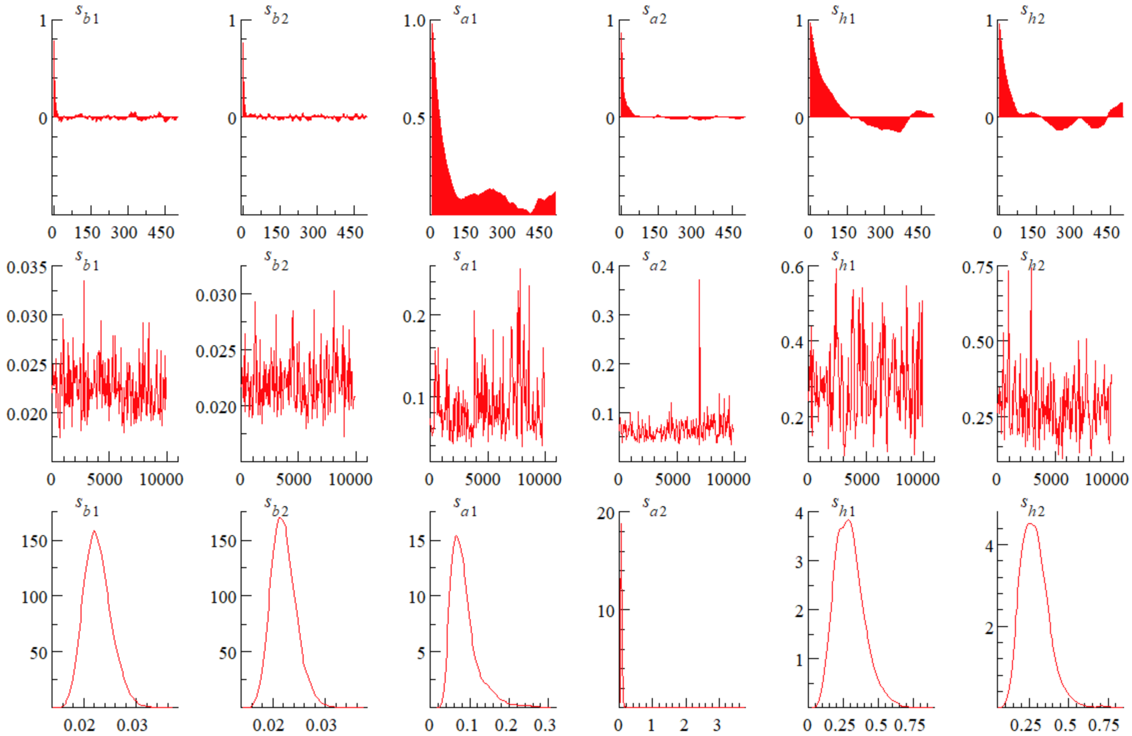

Figure 4. Autocorrelation samples, paths, and posterior density of MCMC estimation.

Note: The six columns from left to right refers to the sample autocorrelations, paths, and posterior density of (∑β)1, (∑β)2, (∑a)1, (∑a)2, (∑h)1, and (∑h)2.

Table 3 presents the estimation results for the selected parameters in the TVP-VAR model for crude oil prices and Bitcoin, respectively, based on MCMC. The posterior means of the selected parameters are positive and lie within the 95% confidence interval. Furthermore, Geweke's CD test indicates that the null hypothesis for all parameters remains accepted at the 95% confidence level, as it cannot be rejected, suggesting that the MCMC algorithm has produced valid posterior results. All parameters are below 100, indicating lower inefficiency factors. These results imply that the MCMC method can effectively estimate parameters in this study.

Table 3. Model parameter estimation results.

Parameter	Mean	Std. dev.	95%L	95%U	Geweke	Inef.
sb1	0.0227	0.0026	0.0182	0.0283	0.178	7.2
sb2	0.0221	0.0024	0.018	0.0275	0.713	9.11
sa1	0.0863	0.0369	0.0431	0.1857	0.588	94.93
sa2	0.0664	0.0621	0.0386	0.1083	0.066	20.90
sh1	0.2935	0.1052	0.1246	0.5387	0.464	88.45
sh2	0.2864	0.0905	0.1473	0.4912	0.150	53.21

4.3. Time-Varying Impulse Response Analysis

To further illustrate the model, we use Figures 5 and 6 to depict the two impulse response functions i the TVP-VAR model. Figure 5 reflects the impulse response time series of a unit standardized positive shock across various lead times, with lead times of 1, 2, and 3 periods, respectively. Figure 6 shows the impulse responses formed by shocks at different time points. To highlight the impact of significant events, this paper selects September 2017 (China bans ICOs), January 2020 (outbreak of COVID-19), and February 2022 (outbreak of the Russia-Ukraine war) as key points, as these are crucial and representative moments for the EPU, Bitcoin, and crude oil price markets, holding significant research value. Next, each time point will be analyzed in detail.

4.3.1. Time-Varying Characteristics Analysis of Impulse Response at Different Lead Times

The impulse response outcomes are evaluated for different lead times, specifically 1, 2, and 3 periods into the future, by estimating the TVP-VAR model. As illustrated in Figure 5, three shocks were applied at different points in time. The trends in the impulse response function exhibit significant differences, which are mainly related to the high volatility of Bitcoin, a non-traditional financial asset. From a detailed analysis, this impact is very evident, with EPU's impulse response to Bitcoin at 1 period ahead being mostly negative before 2021 but generally forming a "W" shape, with the negative impact peaking around June 2017 and turning positive from the beginning of 2021.

As suggested by Baur and Lucey (2010) as an asset may be considered a hedging instrument if it is negatively correlated with other assets under normal market conditions. Thus, based on our analysis, Bitcoin can act as a hedge against crude oil prices to some extent in the short run. Our findings contrast with prior studies, such as Choi and Shin (2022), which indicated that Bitcoin failed to exhibit safe-haven properties in response to financial uncertainty shocks. In Figure 5, the impact of EPU on crude oil prices appears more monotonic, with its one-period-ahead effect showing strong hedging characteristics, being mostly negative throughout the study period, then turning positive between 2017 and 2021, and generally exhibiting an inverted-U shape, with its positive impact peaking around March and April 2018. In contrast, its two-period-ahead impulse effect is much weaker, demonstrating strong safe-haven properties, with crude oil prices reaching $110 per barrel around February 2022. Based on the analysis conducted, it can be concluded that EPU can act as a short-term safe haven for oil. However, in the long term, Bitcoin cannot be considered a safe haven for crude oil prices nor an effective hedge against the stock market during the COVID-19 pandemic and the Russia-Ukraine war. This finding aligns with prior research indicating that Bitcoin is a poor hedging instrument (Bouri, Jalkh, Molnár, & Roubaud, 2017) and not a safe haven (Klein, Thu, & Walther, 2018; Long, Pei, Tian, & Lang, 2021). Furthermore, the impacts of EPU on BTC are predominantly negative.

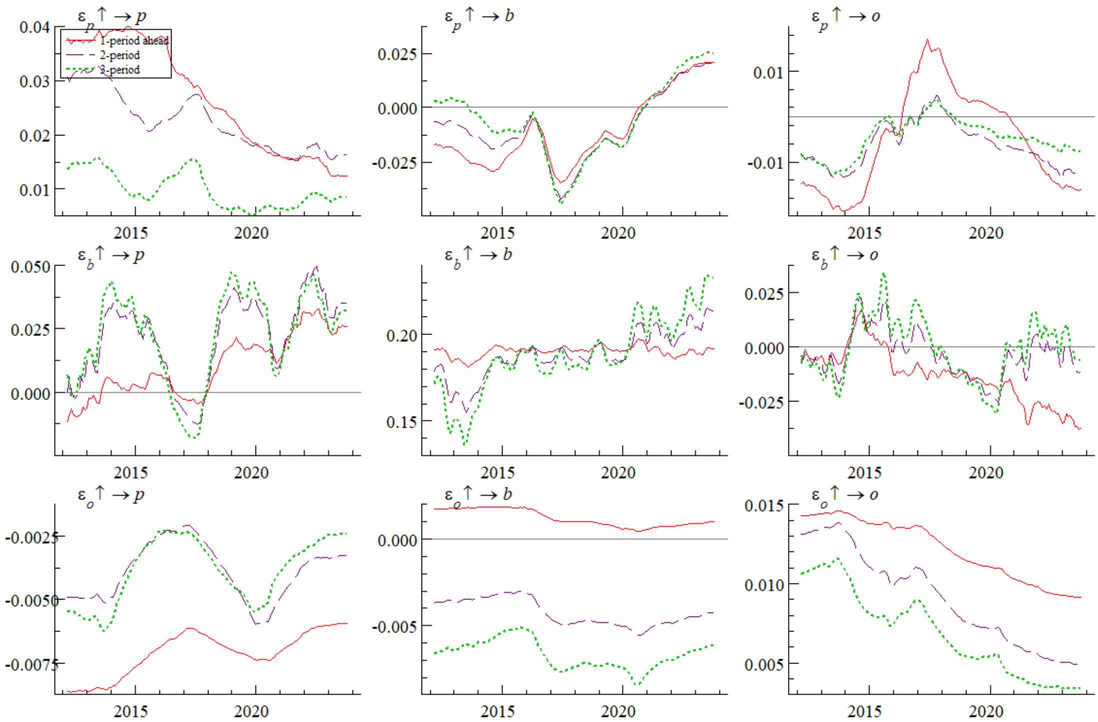

Figure 5. Impulse response function for time-point exogenous shocks.

Note: b represents Bitcoin; p represents EPU; o represents Oil.

4.3.2. Time-Varying Characteristics Analysis of Impulse Response at Different Time Points

Next, we discuss the impulse responses at different time points. Figure 6 illustrates the impulse responses generated by shocks at various times in our study, specifically September 2017 (China bans ICOs), January 2020

(COVID-19 outbreak), and February 2022 (Russia-Ukraine war outbreak). These events are significant in Bitcoin's development, and each moment is highly representative. In the following section, we will conduct a detailed analysis of each time point.

September 2017 marks our initial point in time, representing a period of intense volatility in Bitcoin's bull market, often referred to as "9.4," when Bitcoin prices fell by more than 30%, with even greater declines in other alternative coins. The primary reason was the announcement by the People's Bank of China and seven other ministries on September 4, 2017, explicitly banning ICOs, which triggered strong market panic.

Our analysis reveals that EPU has the most significant and negative impact on Bitcoin prices at Future 0, with the most negative impact. This negative impact diminishes at Future 1 but increases again in the next two periods before gradually decreasing. This suggests that EPU and Bitcoin can provide a certain level of hedging, with the largest effect during these three periods. The Bitcoin market's immaturity (Su et al., 2023) and the frequent sharp price fluctuations (Asimakopoulos, Lorusso, & Ravazzolo, 2023; Bouri & Jalkh, 2023; Song, Chen, & Wang, 2023) contribute to this phenomenon. At this time, EPU has a positive impact on crude oil prices in the future. This impact reaches its peak in the first future period before declining, and by the sixth future period, the impact becomes zero. This indicates that EPU can have a certain short-term impact on crude oil prices, but it is unstable, whether positive or negative, tending towards zero by the sixth period.

January 2020 marks our second time point, a very significant one marked by a global economic panic due to COVID-19. This led to an increased demand for Bitcoin as a safe-haven asset (Bahloul, Mroua, Naifar, & Naifar, 2022; Sarkodie, Ahmed, & Owusu, 2022; Terraza, Boru İpek, & Rounaghi, 2024). Bitcoin, referred to as "digital gold" (Qin, Su, Wang, & Doran, 2023), has been validated for its resilience during severe market downturns, used for hedging and safe harbor purposes (Beneki, Koulis, Kyriazis, & Papadamou, 2019; Das et al., 2020; Wen et al., 2022; Zeinedini, Karimi, & Khanzadi, 2022).

The Federal Reserve's policy of maintaining low-interest rates in 2021 to support economic recovery further contributed to this scenario. At this time, the impact of EPU on Bitcoin was initially negative at the 0 period, reaching its maximum negative impact. In contrast, EPU had a positive impact on crude oil prices at the Future 0 period, which turned negative in the future period 2 and then approached zero by the future 5 period. During this period, crude oil prices hit a short-term low before rebounding, influenced by persistent inflation and geopolitical factors such as the disruption of Russia's gas supplies to Europe, which kept crude oil prices high.

February 2022 marked the third key time point, coinciding with the onset of the Russia-Ukraine conflict. This geopolitical crisis, along with resulting economic sanctions, exacerbated market panic (Kumari, Kumar, & Pandey, 2023; Su et al., 2023). In the eighth week of 2022, at the onset of the conflict, the impact of EPU on Bitcoin follows a pattern similar to other points; the effect of EPU is consistently positive. The increase in Bitcoin's demand and price during the early stages of the war is attributed to its ease of asset transfer. The EPU had a positive effect on crude oil prices during the initial period, turned negative in the subsequent period, and exhibited the greatest negative impact among the three time points, indicating that during special periods like wars, EPU's hedging impact on energy is significant (Yousaf, Riaz, & Goodell, 2023).

The impact then gradually diminished, reducing to nearly zero by the seventh period. The war had a significant impact on crude oil prices, surpassing the impact of other events (Adekoya, Asl, Oliyide, & Izadi, 2023; Sokhanvar & Lee, 2023; Song, Chen, Wang, & Wang, 2022; Zhang, Wang, Xiao, & Zhang, 2023). Similar to Bitcoin, the demand for oil increases with the outbreak of war, leading to a rise in crude oil prices.

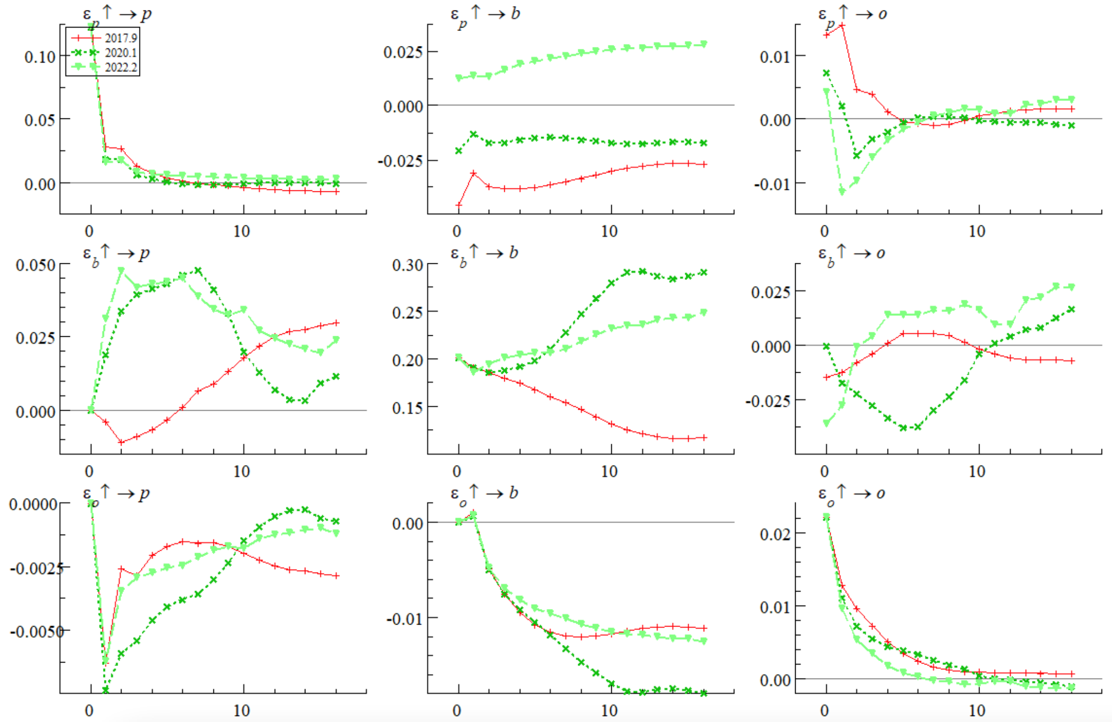

Figure 6. Impulse response function for shocks at different time points.

Note: b represents Bitcoin; p represents EPU; o represents Oil.

5. CONCLUSIONS

Over a decade of development, Bitcoin has always been a contentious entity. While experiencing significant price volatility, it has also witnessed the spread of the COVID-19 pandemic and the outbreak of the Russia-Ukraine war, events closely related to energy prices. The ongoing COVID-19 pandemic and the Russia-Ukraine war-related turmoil provide a critical experimental platform for researching Bitcoin's role as a safe-haven asset in the context of global crude oil prices related to EPU. However, research in this area remains scarce. Moreover, there is insufficient focus on whether significant events like the COVID-19 pandemic and the Russia-Ukraine war have dominated the relationship between Bitcoin and crude oil prices. More importantly, the extent of Bitcoin's evolution under market conditions and specific events remains overlooked. This paper extends the research field by studying the dynamic relationship between EPU, Bitcoin, and crude oil prices across the entire data distribution, and how these relationships evolve with changing market conditions.

We have analyzed how uncertainty affects the time-varying relationship between Bitcoin and oil price markets under different circumstances. We adopted the TVP-VAR model to analyze impulse responses and studied the impact of EPU on Bitcoin and crude oil prices at different times, especially considering whether special event periods such as the COVID-19 pandemic and the Russia-Ukraine war have significant impacts on the Bitcoin and oil price markets. Our analysis focuses on the time-varying effects of EPU on Bitcoin and crude oil prices across different lag periods. The dynamic effects of EPU on Bitcoin and crude oil prices are significantly different. Compared with oil, the short-term effects of EPU on Bitcoin are more stable, but at different special time points such as the COVID-19 pandemic period, the effects of EPU on Bitcoin are more lasting. Additionally, from the perspective of hedging, Bitcoin can act as a safe haven asset for oil in the short term, which also verifies the hedging properties of Bitcoin. Specifically, during periods of severe pandemic spread and the Russia-Ukraine war, Bitcoin's hedging properties against other markets are enhanced, and its hedging effects on the crude oil market subsequently increased. Before the outbreak, Bitcoin showed good hedging effects against the oil market.

This study establishes the impact of EPU on Bitcoin and crude oil prices, which are energy commodities, and may provide insights into the recently widely discussed topic of Bitcoin government regulation. These findings are crucial for policymakers and investors, especially regarding the stability of the interconnection between EPU and the Bitcoin market. Policymakers need to pay further attention to the dynamic connections among EPU, Bitcoin, and energy markets. Indeed, policymakers should clearly understand the pathways of various markets, especially under extreme market conditions. Therefore, they should intervene appropriately after extreme negative or positive events occur, introducing regulatory policies. Investors can identify the dynamic connections between Bitcoin prices and other factors to assess investment decisions. The dynamic relationship allows for an analysis of hedging possibilities between markets at different time points. A comprehensive assessment will help investors make informed investment decisions from different temporal perspectives. Although Bitcoin is an anonymous currency, government agencies can monitor trading platforms to prevent transactions from affecting its value. It is recommended to include Bitcoin in macro-prudential risk prevention and control indicators. Moreover, the results regarding Bitcoin's hedging role provide valuable insights for investors in hedging portfolio risks. Understanding the nature of the interrelationships between assets is crucial for effective risk management.

While the findings of this study reveal some important insights into the dynamic effects of the EPU, Bitcoin, and energy markets, it overlooks the sustainability of these dynamic effects and does not explore the changes in risk contagion paths across different periods. To further investigate the causal effects, future research could apply techniques based on quantile vector autoregression and multiscale coherence to study cryptocurrency market spillovers. Additionally, including different cryptocurrency markets for comparison could yield more interesting findings, which might serve as another theme for future research. Our results provide a direction for future studies, which could incorporate research on other energy products and Bitcoin returns in specific markets, as well as local energy commodity market returns. This could be impactful, as local energy prices differ from international energy prices. Investigating the sustainability of Bitcoin in the future is crucial. Specifically, we suggest analyzing the sustainability of the cryptocurrency market beyond Bitcoin, considering the characteristic differences between various cryptocurrency assets. This calls for more research, especially regarding the impact of systemic risks and alternative measures of uncertainty within the cryptocurrency market (Lucey et al., 2022). As new blockchains gain prominence and interact with other digital assets, it is crucial that these factors be considered in both academic and policy research.

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Data Availability Statement: Upon a reasonable request, the supporting data of this study can be provided by the corresponding author.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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