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Correlations and volatility spillovers across cryptocurrency and stock markets: linking gold, bonds, and FRX

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Abstract: This study examines the connectedness among Bitcoin, gold, equity, bonds, and dollar to Ruble exchange rate volatility in the context of new developments during Russia Ukraine conflict using daily data from January 1, 2018, to May 30, 2023. Three GARCH estimation models are utilised to capture the volatility spillover effect among the underlined assets, and assess for the hedging, diversification, and safe haven properties of assets in the context of Russian financial market. The results indicate that the Bitcoin exhibits hedging ability that enables investors to diversify the risk among the underline financial assets. In addition, VaR and CVaR estimations are employed to estimate potential losses in the portfolio during the crisis, where we observe significant increase in Bitcoin investments during crisis, where negative news has a stronger impact compared to positive news, which underscores the importance of prudent asset allocation for risk mitigation. The study provides notable policy implications within the context of the ongoing crisis between Russia and Ukraine.

Keywords: Bitcoin; gold; equity; bonds; USD/RUB exchange rate: Russian financial market; GARCH estimation; hedging and diversification.

JEL codes: C11, C60.

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1 Introduction

Bitcoin, the world's pioneering decentralised digital currency, has garnered substantial popularity and growth including its potential as a store of value, decentralised in nature, and secured by blockchain technology. Bitcoin demonstrated remarkable volatility and an upward trajectory in price and returns (Baur et al., 2018). Bitcoin attracted significant attention from investors as it is considered as an alternative of investment with conventional financial assets. During COVID-19 pandemic price of Bitcoin recorded an all-time high. However, it subsequently experienced a correction during the bearish market, as Bitcoin has undergone several price cycles characterised by notable rallies and corrections due to its highly volatile and unconventional price fluctuations. Bitcoin is now considered as a digital currency, an alternative investment, and a hedge against traditional financial assets (Dyhrberg, 2016b). In this context, the current study aims to analyse the correlation of Bitcoin with gold, equity, bonds, and exchange rates after the conclusion of the COVID-19 pandemic, and during the Russia-Ukraine conflict (2022). The study focuses on the Russian financial market to examine Bitcoin hedging and risk diversification ability during crisis.

Bitcoin's performance is intricately influenced by a myriad of factors, encompassing market sentiment, regulatory developments, technological advancements, and the dynamic landscape of geopolitical conditions. The correlation between Bitcoin and traditional assets such as gold, equity, bonds, and exchange rates are characterised by a notable degree of variability over time. Research conducted by Bouri et al. (2020) has shed light on a weak correlation among gold, equity, and commodities, indicating independent price movements in these markets. Similarly, the study by De Pace and Rao (2023) reported a weak correlation between Bitcoin and traditional assets like gold, stocks, and other commodities. These findings suggest that Bitcoin's price movements may not necessarily align with those of traditional financial instruments. In the realm of bonds, Baur et al. (2018), Fang et al. (2019), and Hassan et al. (2022) have collectively revealed a low connectedness between Bitcoin and bonds. This implies that while bonds are typically recognised as stable income-generating assets, Bitcoin, in contrast, is characterised by its inherent volatility and speculative nature. The intricate interplay of various factors and the dynamic nature of Bitcoin's correlation with traditional assets underscore the complexity of its behaviour within the broader financial landscape. These insights contribute to a nuanced understanding of Bitcoin's position in the investment ecosystem.

The correlation of Bitcoin and exchange rate is closely linked due to payment in cross currency. In doing so, the pressure on the ruble and its continuous depreciation in the

context of the current conflict with Ukraine, examining the correlation between Bitcoin and exchange rates is of particular importance in this study. Therefore, it is crucial to investigate whether investors turn to Bitcoin as an alternative store of value during this crisis. Studies have demonstrated a positive correlation between exchange rates and Bitcoin during times of crisis (Li et al., 2022). However, the correlation between Bitcoin and exchange rates is contingent upon regional factors (Ben Nouir and Ben Haj Hamida, 2023), market dynamics (Khan et al., 2022). It is important to note that correlations between Bitcoin and exchange rates are not static for every economy, and it is potentially influenced by various factors, such as market conditions, regulatory developments, macroeconomic events, and media attention (Mensi et al., 2023).

During economic crises, such as the pandemic of COVID-19 and the Russian-Ukraine conflict in 2022, the Bitcoin observed as financial independent tool (Girardone, 2022). Particularly in the Russian economy that faces strict economic sanctions Bitcoin provide capital protection (Ghorbel et al., 2022a), reliable mean for cross-border transactions un-censorable payments system (Beraich et al., 2022) for investors. Geopolitical developments and subsequent responses from the Russian government alter the dynamics of the ongoing conflict significantly affected the Russian financial with heightened volatility (Boubaker et al., 2023). Additionally, the ruble has faced depreciation pressure against the US dollar, while the uncertainty surrounding future prospects has affected business activities and investments by eroding investor confidence.

The performance of Bitcoin in terms of increased price and returns appears to surge. Previous research on the relationship between Bitcoin and financial markets in various countries has primarily focused on Bitcoin's price dynamics (Dyhrberg, 2016a). The examination of risk and return is conducted within the context of determining whether Bitcoin can function as a safe-haven asset, a hedging tool, or a decentralised asset. With the continuous development of the modern financial markets, where cryptocurrencies have gained a strong position in financial asset management, portfolio diversification is becoming increasingly enriched. The increasing interconnectivity among assets and markets is leading investors to allocate assets across borders, especially including Bitcoin in their portfolios (Wang et al., 2019). Despite the rapid developments in the financial market, the possibility of external shocks due to the economic crisis affecting portfolio allocation remains unexamined.

Conducting this research study serves multiple objectives that motivate the authors to focus on the Russian financial market. Firstly, Russia's role as a major exporter of diverse assets, including minerals, energy, and commodities, attracts significant global investors. Secondly, the Russian economy faces challenging economic sanctions from Western allies and the USA due to conflicts with other nations, leading to a continuous struggle in the exchange rate between the ruble and the US dollar. Lastly, the combination of the COVID-19 epidemic and the Russia-Ukraine conflict sets the Russian financial market apart from others, making it a crucial area for examination.

The key finding of this study indicates that Bitcoin can be used as a hedging tool in the Russian financial market, exhibiting correlations with MOEX equity, Russian government ten-year bonds, and the USD/RUB exchange rate. Additionally, Bitcoin possesses properties of a safe haven, allowing for risk diversification among other financial assets in the portfolio. We calculate the value at risk (VaR) and conditional value at risk (CVaR) using the Cornish-Fisher expansion for Bitcoin and other underlying assets to estimate potential losses in the selected portfolio. During the conflict with

Ukraine in 2022, a notable surge in investments in Bitcoin was observed in the Russian financial market, leading to increased volatility and uncertainty in financial assets. These assets exhibited a stronger response to negative news compared to positive news. Consequently, it is imperative to exercise caution and allocate assets prudently to mitigate risk. The study offers significant policy implications within the framework of the ongoing crisis between Russia and Ukraine in 2022.

This article significantly contributes to financial economic literature on multiple fronts. *Firstly*, the empirical study delves into the examination of crypto assets, particularly Bitcoin (BTC), against the backdrop of the concurrent global health crisis of the COVID-19 pandemic and the heightened regional conflict between Russia and Ukraine in 2022. *Secondly*, the study scrutinises the relationship between BTC and key financial assets, encompassing gold, equities, bonds, and the USD/RUB exchange rate. The selection of these key financial assets is based on their capital size and significance in portfolio investment decision-making within the Russian financial market. *Thirdly*, this research empirically explores the potential prowess of the aforementioned assets for hedging and diversification amid the uncertainties prevailing in the economic market, employing advanced econometric estimation techniques, specifically GARCH estimation models. To facilitate accurate risk and volatility measurement for fund allocation during crises, this study offers practical recommendations to investors in the Russian financial market and trading partners. *Finally*, the study conducts risk and return assessments for existing leverage levels of investment, utilising econometric estimation tools such as VaR and CVaR. These estimations are developed by following the seminal research work of Bardou et al. (2008) and Lai and Xing (2014). The comprehensive insights provided in this article not only enhance our understanding of the dynamics between crypto assets and traditional financial instruments but also offer valuable guidance for decision-makers and investors in navigating the complexities of the contemporary economic landscape.

The structure of the remaining work is as follows: Section 2 provides a comprehensive literature review, Section 3 introduces the models utilised in this study, Section 4 outlines the data used, and Section 5 presents the methodology employed. Section 6 concludes the paper and offers suggestions for international and Russian investors to navigate various market situations.

2 Literature review

Bitcoin has shown potential value for investors during crises and in sanctioned economies. Ghorbel et al. (2022b) examined its use as a hedge against inflationary pressures. Diniz-Maganini et al. (2021) highlighted its decentralised and borderless nature, enabling cross-border transactions without traditional banking channels. In sanctioned economies, Bitcoin serves as a financial asset for peer-to-peer transactions across borders, bypassing third-party intermediaries (Jin et al., 2022). It offers a faster and more accessible option for remittances (Wang et al., 2022) and provides a level of financial privacy in economies with surveillance or restrictions. Furthermore, Bitcoin offers investment opportunities for diversification beyond traditional assets in sanctioned economies like Russia. However, its use in the Russian financial market faces challenges such as regulatory developments, technological limitations, cybersecurity concerns, and price volatility. This study provides suggestions for investors to consider these factors in the context of crises and sanctioned environments in Russia.

Since its invention by Santoshi Nakamoto in 2009, Bitcoin has gained popularity due to its unique features, including peer-to-peer decentralisation and secure transactions (Goodell et al., 2022). Its independence from government involvement and taxation has made it a preferred option for transactions where traditional financial systems may not be accessible. Investors have started using Bitcoin as an alternative to cash transfers, especially during periods of sanctions and crises. Academic scholars have extensively researched the correlation between Bitcoin and other financial assets, particularly in terms of dynamic correlations.

Research on the dynamic correlation between Bitcoin and traditional assets suggests that Bitcoin is relatively independent and exhibits a weak relationship with other financial assets. Sohail et al. (2023) and Ullah et al. (2023a, 2023b) found a weak and time-varying relationship between virtual currency and traditional assets using Copula estimation methods. The relationship between Bitcoin and other assets is susceptible to external events such as the Russia-Ukraine crisis, where Bitcoin can be used as a decentralised tool but not as a hedging tool. Jin et al. (2022) explored the causal relationship between Bitcoin and other financial assets using data-driven directed acyclic graph methods, revealing Bitcoin's overall independence but a lagging relationship with other assets in bear markets. Ghorbel et al. (2023a) conducted Granger causality and co-integration tests and found no stable long-term relationship between Bitcoin and gold, crude oil, stocks, savings, and exchange rates in the US market. However, in the short-term, stocks and exchange rates positively affect Bitcoin, while interest rates have a negative impact. Corbet et al. (2018) analysed frequency domain and concluded that Bitcoin exhibits a significant level of independence from investable assets in the US financial market, providing diversification benefits for short-term investment. Ullah et al. (2022) and Sohail et al. (2021) identified a spillover effect between Bitcoin and the US market.

In terms of Bitcoin's role in asset portfolios, researchers focus on its potential as a safe-haven asset, hedging tool, and diversification tool. Wu et al. (2021) found that while Bitcoin lacks the function of a currency, it enhances the effectiveness of asset portfolios. Karim et al. (2023) utilised Copula and ADCC-EGARCH models and observed an extremely strong time-varying correlation between Bitcoin and the S&P 500 index, suggesting its potential as a risk hedging and diversification tool. Boubaker et al. (2023) examined the distribution of Bitcoin in the asset portfolios of American investors and highlighted its significant diversification benefits due to its high yield and high-risk characteristics. The outbreak of the COVID-19 pandemic and the Russia-Ukraine conflict in 2022 served as major external shocks to the financial market, increasing the risk level of domestic and global markets. Investors have become more interested in incorporating Bitcoin into their asset portfolios to mitigate losses during crisis periods and protect their portfolios.

Numerous scholars have conducted research on the impact of the COVID-19 epidemic (Zhang and He, 2021) and the recent crisis between Russia and Ukraine. Corbet et al. (2018) focused on the Dow Jones Industrial Index, WTI Crude Oil, MOEX stock index, Shenzhen Component Index, and gold to study the influence of Bitcoin on COVID-19 using GARCH and DCC-GARCH models. Chemkha et al. (2021) highlighted the significant impact of the Russian-Ukraine conflict on the energy market, examining the contagion effect among major assets and the changing volatility relationship between the Russian stock market and Bitcoin. However, the competition of Bitcoin with mainstream assets remains uncertain, emphasising the importance of careful portfolio

diversification. Bardou et al. (2008) employed VaR, CVaR, MVaR, and MCVaR measures to examine the hedging and diversification properties of Bitcoin in comparison to US 10-year Treasury Bonds. Jin et al. (2022) used the GARCH model to study the risk relationship between Bitcoin and the S&P 500 during the COVID-19 epidemic. The results indicated that Bitcoin cannot serve as a safe-haven asset when market risk increases, and even a small amount of Bitcoin in the asset portfolio can amplify the downside risk. Goodell et al. (2022) tested the effectiveness of Bitcoin in the context of the COVID-19 epidemic using the GARCH model. They found that Bitcoin has a significant impact on the MSCI China index and industry index, acting as a weak hedging tool and a potential weak safe-haven asset during market crises.

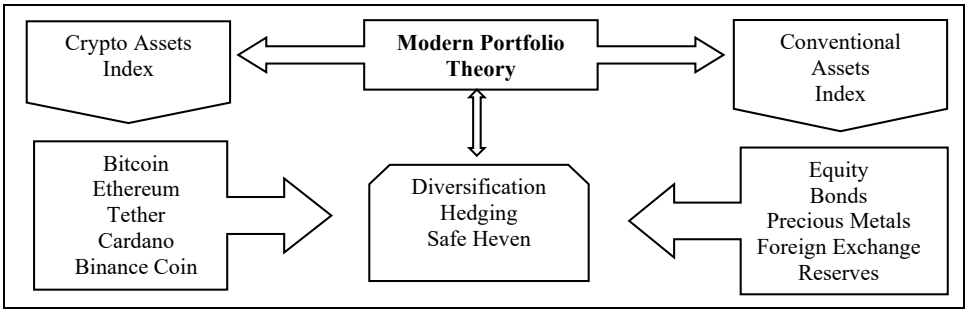
In the existing literature, various methods have been used to describe the correlation relationship of fluctuations in financial markets. The GARCH family model is commonly employed to capture asset volatility. The correlation between Bitcoin and exchange rates is important for portfolio diversification, particularly in the context of historical fluctuations between rubles and the US dollar. The GARCH model, proposed by Bollerslev (1986), assumes that stock and exchange rate return series follow a normal distribution and incorporates an unobservable error term in the conditional variance equation. However, the standard GARCH model fails to account for asymmetrical fluctuations, necessitating the use of asymmetric GARCH models. The EGARCH model, introduced by Nelson (1991), addresses dynamic asymmetry by adding exogenous variables to the mean equation. Similarly, the GJR-GARCH model, proposed by Glosten et al. (1993), incorporates asymmetrical assumptions and performs well in capturing market shocks. To study the dynamic correlation between Bitcoin and other assets, Bouri et al. (2022) utilised the DCC-GARCH model and observed a weakening correlation between Australian litigation funds and Bitcoin since the outbreak of COVID-19. Ghorbel et al. (2022a) employed the MS-GARCH model and found that Bitcoin cannot be regarded as a substitute for WTI crude oil and US natural gas spot during the COVID-19 epidemic. Goodell et al. (2022) utilised the TV-MS-GARCH model with multiple distributions to examine the relationship between Bitcoin price, transaction volume, and Google search volume.

2.1 Theoretical background

This study draws support from Harry Markowitz's 1952 modern portfolio theory, highlighting investor rationality and the use of market information for constructing investment portfolios. The theory guides asset weight allocation based on associated risks and introduced hedging and diversification concepts for risk management. Econometric estimations in this study strategically guide hedging and diversification among Bitcoin, gold, equity bonds, and exchange rates in the Russian financial market. The aim is to provide investment allocation suggestions to investors and fund managers. Through constructing a portfolio with non-perfectly correlated assets, the study addresses current risk levels. Weight allocation to securities utilises the mean-variance model, aiming to maximise expected return while minimising total investment variance. Figure 1 depicts the theoretical framework, analysing investor preferences, market information, market efficiency, and strategic positioning, including hedging and diversification. Bitcoin's role in portfolios is undetermined, relying on changes in dynamic correlation. Investigating this correlation is crucial for understanding its impact on Russian investors' portfolios, especially given Russia's status as a major energy and commodity exporter. The study

addresses external shocks like the COVID-19 epidemic and Russia-Ukraine conflict 2022, aiding global and regional investors in adjusting portfolios and mitigating risks.

Figure 1 Theoretical framework of the study (see online version for colours)



Source: Authors' calculation

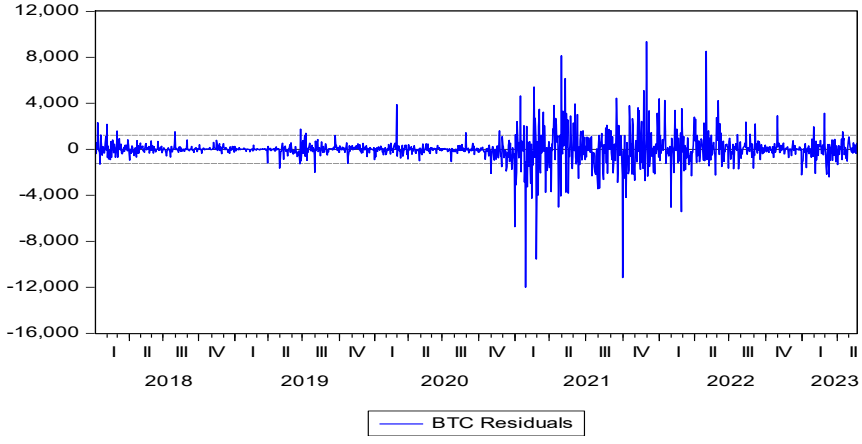
3 Methodology

This research study aims to analyse the relationship between Bitcoin and the main assets in the Russian financial market, specifically focusing on the MOEX stock index, gold spot-trading, MOEX ten-year bonds index, and the exchange rate of the US dollar into rubles. The study considers these variables as exogenous and examines their correlation with other underlying assets during the crises of the COVID-19 epidemic and the Russia-Ukraine conflict in 2022. Dummy variables (D1 and D2) are used to compare changes in the asset relationships.

3.1 Data description

The study utilised daily closing price data from the well-known cryptocurrency website, Coin Market Cap https://coinmarketcap.com for Bitcoin. The data for other financial assets were derived from the Moscow stock exchange (MOEX), starting from January 1, 2018, to May 30, 2023, resulting in a total of 1,340 observations. Figure 2 shows the volatility of the return of Bitcoin in response to the crisis. The motivation for selection of the data time-period is to examine the possible impact of COVID-19 and Russian Ukraine conflict (2022). The study specifically used the MOEX Russia Index[1] for the stock market, gold spot-trading (RUB per gram), the MOEX 10-years government bond index, and the USD to Rubles exchange rate. The analysis considered the global pandemic outbreak starting from December 31, 2019, and two windows were selected to conduct a comprehensive examination and capture the interactions among the indices. As the prices of the selected indices differ significantly from those of other financial assets, logarithmic rates of return were employed to calculate the price data, preventing parameter values from becoming excessively large.

Figure 2 Response of Bitcoin to COVID-19 and Russia Ukraine conflict (see online version for colours)



Source: Author's calculation

3.2 Model specification

To measure volatility persistence, the study applies the ARX-GARCH model proposed by Bollerslev (1986). Furthermore, the study utilises VaR and CVaR, proposed by Nelson (1991), to assess the risk associated with the selected assets and asset pairs for portfolio diversification. Previous studies have employed GARCH models to analyse financial time series but considering the potential structural changes following consecutive crises in the Russian financial market, this study employs the ARX-GARCH, GJR-GARCH, and E-GARCH models to examine short and long timescales. These models can account for unknown parameters that occasionally emerge in the market at unspecified times. Given the high volatility and susceptibility of the Bitcoin market to small market changes and its potential impact on positive and negative information shocks, this paper employs the ARX-GARCH (1,1)-t, ARX-GJR-GARCH (1,1)-t, and ARX-EGARCH (1,1)-t models to investigate the effects of each market before and after the health and peace crises.

$$Rt = \ln(Pt / Pt - 1) \times 100 \tag{1}$$

where the Pt represents the asset price at specific time interval, and Rt is the logarithmic rate of return. For the convenience of expression, various assets are abbreviated as BTC for Bitcoin, GLD for gold, STC for stock, BND for bonds and FRX for exchange rate of USD/RUB are used in the tables and figures.

3.3 ARX-GARCH (1,1)-t model

The study express of the ARX-GARCH model is as follows:

$$R_{it} = \mu + \varphi Rt - 1 + \beta 1 + \beta 2(D1, t \times Rm, t) + \beta 3(D2, t \times Rm, t) + \varepsilon_{it} \tag{2}$$

Given that the $\omega > 0$, $\alpha 1 \geq 0$, $\beta 1 \geq 0$, $\alpha 1 + \beta 1 < 0$ while is the Rt = the rate of return for Bitcoin along with this the μ is the mean of the model and Rm is the rate of return for all

the other assets. m = 1 – 4 represents the four assets to be studied, the first dummy variable (D2) is employed to gauge the influence of the COVID-19 economic outbreak on the change in returns for the specified assets. Simultaneously, the second dummy (D2) variable is utilised to assess the impact of the war period on the performance of the underlying asset. Notably, this analysis extends beyond the crisis period and encompasses the subsequent war period, allowing for a nuanced understanding of the sustained effects on asset performance, εt represents the residual, and ht is the conditional variance used in the econometric model.

$$H_{it} = \omega + \alpha 1 \varepsilon 2t - 1 + \beta 1 ht - 1 \tag{3}$$

3.4 GJR-GARCH (1,1)-t model

This model estimated to examine the possible asymmetric conditional variance within the preview of all assets utilised in the study:

$$Ht = \omega + \alpha 1 \varepsilon 2t - 1 + \gamma 1 It - 1 \varepsilon 2t - 1 + \beta 1 ht - 1 \tag{4}$$

Among them, $\omega > 0$, $\alpha 1 \geq 0$, $\beta 1 \geq 0$, $\alpha 1 + \gamma 1 \geq 0$, $\alpha 1 + \beta 1 < 1$. It is the threshold item, $\varepsilon t < 0$ means bad news, $\varepsilon t \geq 0$ means good news, $it = 0$. Specific to the impact on the conditional variance, when the market is favourable, the coefficient of the volatility item is $\alpha 1$, and when there is a negative market, the coefficient of the volatility item is $\alpha 1 + \gamma 1$. The response of the variance to the information shock is asymmetric, if and only if the coefficient of the threshold term $\gamma 1 \neq 0$. Since the model adds an asymmetric factor to the conditional variance, it can extract the information impact curve from it, and the relationship between the residual and the conditional variance. The correlation relationship is described. The horizontal axis of the information impact curve is the residual, and the positive and negative values can be regarded as positive and negative information; the vertical axis is the conditional variance, which measures. Therefore, the information shock curve can reflect the correlation between positive and negative information and volatility. Due to the existence of asymmetric factors, it makes the image asymmetric, so that the leverage effect of the research object can be analysed.

3.5 E-GARCH (1,1)-t model

The first half of the model is the same as formula (1), the difference is that in order to ensure that the conditional variance is non-negative; the natural pair is taken on the left side of the conditional variance equation number, namely:

$$Lnh2t = \omega + \alpha 1 \varepsilon t - 1 ht - 1 + \gamma 1 \varepsilon t - 1 ht - 1 - \mu + \beta 1 \ln h2t - 1 \tag{5}$$

Here the, $\omega > 0$, $\alpha 1 > 0$, $\beta 1 \geq 0$, $\varepsilon t - 1$ $ht - 1 - \mu$ is the ARCH term of the model, $\varepsilon t - 1$ $ht - 1$. It is used to describe the difference between good news and bad news in the model. When $\varepsilon t - 1$ $ht - 1 > 0$, it means good news. At this time, the right side of formula (4) is $\omega + (\alpha 1 + \gamma 1)$ $\varepsilon t - 1$ $ht - 1 - \gamma 1 \mu + \beta 1$ lnh $2t - 1$; when $\varepsilon t - 1$ $ht - 1$. When < 0, it means negative news, the right side of formula (4) $\omega + (\alpha 1$ – gamma 1) $\varepsilon t - 1$ $ht - 1 - \gamma 1 \mu + \beta 1$ lnh $2t - 1$.

3.6 VaR and CVaR

Following the Russian financial market which is facing the price and volatility risks associated with the uncertain market conditions. VaR and CVaR (Bardou et al., 2008) are certainly the most suitable and reliable risk measurement estimation tools used for market in similar conditions such as Russian financial market, especially for the evaluation of extreme losses potentially faced to the investors in Russian financial market. In line with other crisis the risk measures in numerical term are challenge after the crises of COVID-19 and current conflict between Russia and Ukraine (2022). In addition, as discussed, the literature that the return sequence of financial assets does not distribute with standard normal conditions as in our Bitcoin case, whose price has high volatility. Therefore, we use the Cornish Fisher (Maillard, 2012) estimation method for calculation. This study uses the VaR and CVaR measurement estimation to measure the downside risk β of the Bitcoin market under a certain confidence level α during both crises are represented as follows:

$$VaR(\alpha) = -F - 1r(1-\alpha) \tag{6}$$

Among them, *Fr* represents the cumulative distribution function of the portfolio return rate *r*.

Since VaR does not have sub-additivity, and only measures the maximum loss under the confidence level, the additional loss beyond the maximum loss cannot be estimated. Therefore, CVaR, which has subadditivity and can measure excess losses, is often used as a risk measure for asset portfolios. It is defined as follows:

$$\begin{aligned} VaR(\alpha) &= -E(r \mid r \le -VaR) = -\int -VaR - \infty zf\ r(z)dzFr(-VaR) \\ &= -\int -VaR - \infty zf\ r(z)dz1-\alpha \end{aligned} \tag{7}$$

Among them, *Fr*(*z*) is the probability density function of portfolio returns.

4 Results, empirical findings and discussion

The study utilises extended GARCH econometric estimation models to analyse the correlation between Bitcoin and various other financial assets in the Russian financial market, including the MOEX stock index, gold spot-trading, the MOEX ten-year government bond index, and the exchange rate of US dollar to rubles are examined. The focus is on studying the correlation during the COVID-19 epidemic and the Russian Ukraine conflict in 2022, as these crises is expected to impact the correlation among the underlying assets. Additionally, the analysis extends to include different estimation models such as ARX-GARCH, GJR-GARCH, and E-GARCH to assess the risk of Bitcoin in relation to other financial assets. The analysis methods also include VaR and CVaR calculated based on the Cornish-Fisher (CF) expansion. The reason for employing this estimation is to study the external information shocks occurring in response to the ongoing crises.

Table 1 Summary statistics

Summary	*BTC*	*Gold*	*Stock*	*Bond*	*USD/RUB*
Mean	0.313	0.036	–0.019	0.031	0.002
Median	0.087	0.022	0.037	0.051	0.001
Max.	33.679	4.278	5.358	5.412	1.479
Min.	–34.376	–3.712	–7.018	–7.720	–1.070
Std. div.	6.274	0.686	2.241	1.285	0.394
Skewness	–0.607	0.091	–0.651	–0.365	0.301
Kurtosis	8.160	6.217	6.076	4.264	2.538
Obs.	1,340	1,340	1,340	1,340	1,340

4.1 Correlation analysis between Bitcoin and major assets in Russian financial market

According to the descriptive statistics presented in Table 1, Bitcoin exhibits the highest average return rate and the largest standard deviation, indicating that it is a high-yield, high-risk asset. This finding is consistent with conclusions drawn in previous literature. In terms of kurtosis and skewness, Bitcoin, the MOEX Russia stock index, and the MOEX ten years government bond index show negative skewness, indicating a left-skewed distribution. On the other hand, MOEX gold spot-trading and the exchange rate USD/RUB exhibit positive skewness, indicating a right-skewed distribution. Bitcoin also demonstrates the highest kurtosis value, followed by MOEX gold, with both exceeding the level 3.00. The kurtosis of the USD/RUB exchange rate is also close to 3.00, indicating a peaked and heavy-tailed distribution, which aligns with the characteristics of gold. Since skewness of a normal distribution is generally close to 0 and kurtosis is close to 3.00, it can be preliminarily concluded that the data does not conform to the distributional characteristics of a time series.

Table 2 Static correlation coefficients among assets

	BTC	*Gold*	*Stock*	*Bond*	*USD/RUB*
BTC	1.000				
Gold	0.205	1.000			
Bond	–0.006	–0.085	1.000		
Bond	–0.010	–0.078	0.843	1.010	
USD/RUB	0.051	–0.032	–0.025	–0.029	1.000

4.2 Normal distribution

To accurately assess whether the asset return series follow a normal distribution, a normality test is conducted. The Shapiro-Wilk test results indicate that the p-value of the statistics are all small, specifically 0.01, leading to the rejection of the null hypothesis. Hence, it can be concluded that the five asset return series do not adhere to a normal distribution.

To determine if the ARX-based GARCH family model can be established, a stationarity test is performed on the return sequence. The ADF unit root test is employed, where the null hypothesis assumes the presence of a unit root and non-stationarity. The test results reveal significant p-value, leading to the rejection of the null hypothesis. Assuming the return series is normally distributed, an ARX-based GARCH family model is suitable for estimation and analysis. This model investigates the changes in the relationship between Bitcoin and the main assets of the Russian financial market before and after both crises. The parameter estimation results for each asset are presented in Table 3 to Table 6.

Table 3 displays the parameter estimation results for Bitcoin and gold spot-trading, along with the MOEX stock index, MOEX bond index, and the US dollar into rubles exchange rate. Among these assets, the GJR-GARCH model exhibits the lowest logarithmic likelihood function, making it the appropriate choice for analysis. This estimation is in line with the approach used by Yousaf et al. (2022) to examine different assets. Generally, if the underlying assets exhibit negative or uncorrelated relationships, they can serve as mutual hedging tools. In our case, Bitcoin and gold in the Russian financial market are assets that can be utilised for mutual risk-avoidance. Conversely, positive correlation among assets indicates their potential as mutual diversification tools.

Table 3 Parameter estimation results of the main contracts of Bitcoin and gold-spot

Parameter	*GARCH-t*	*GJR-GARCH-t*	*EGARCH-t*
μ	0.084	0.021	0.081
	(0.679)	(0.150)	(0.610)
Φ	–0.009	–0.09	–0.431
	(–0.186)	(–0.148)	(0.762)
α	0.060***	0.080***	0.016
	(0.000)	(2.753)	(0.281)
β_0	0.604***	0.651***	0.873***
	(2.415)	(14.173)	(3,416.196)
β_1	0.810*	0.688**	0.452**
	(46.102)	(2.100)	(3.035)
β_2	–0.310	–0.390	–0.321
	(–0.823)	(–0.360)	(–0.349)
β_3	–0.476	0.027	0.147
	(–0.805)	(0.570)	(4.357)
Ω	0.216	3.240***	0.049***
	(0.769)	(2.815)	(4.356)
Υ		0.876**	0.161***
		(2.036)	(4.423)
Sharpe	3.028***	3.026***	3.728
	(0.00)	(11.655)	(12.341)
Log likelihood	–2,153.266	–2,312.109	–2,107.363

Note: The signs *, **, *** represent the level of significance at 10%, 5% and 1%, respectively.

Based on the parameter estimation results, the estimated values of β_0 and β_1 are significantly positive across all models, suggesting that in the long run, Bitcoin holds a dominant position in the Russian financial market. This can be attributed to the imposition of economic sanctions the suspension of Russia's banking system from SWIFT (Chemkha et al., 2021), which have created challenges for investors in transferring financial deposits. As a result, Bitcoin and gold have emerged as the primary options for investors.

Furthermore, the value of β_2 is negative and statistically insignificant, indicating that Bitcoin was a weak hedging tool for the main gold contract during the crises of the COVID-19 epidemic and the Russian-Ukraine conflict in 2022. However, the value of β_3 is positive but statistically insignificant, suggesting that Bitcoin served as a weak decentralised tool for the Russian gold contract during both crises.

Table 4 Parameter estimation results of Bitcoin and MOEX stock index

Parameter	*GARCH-t*	*GJR-GARCH-t*	*EGARCH-t*
μ	0.084	0.021	0.081
	(0.679)	(0.150)	(0.610)
Φ	–0.009	–0.09	–0.431
	(–0.186)	(–0.148)	(0.762)
α	0.060***	0.080***	0.016
	(0.000)	(2.753)	(0.281)
β_0	0.604***	0.651***	0.873***
	(2.415)	(14.173)	(3,416.196)
β_1	0.810*	0.688**	0.452**
	(46.102)	(2.100)	(3.035)
β_2	–0.310	–0.390	–0.321
	(–0.823)	(–0.360)	(–0.349)
β_3	–0.476	0.027	0.147
	(–0.805)	(0.570)	(4.357)
ω	0.216	3.240***	0.049***
	(0.769)	(2.815)	(4.356)
Υ		0.876**	0.161***
		(2.036)	(4.423)
Sharpe	3.028***	3.026***	3.728
	(0.00)	(11.655)	(12.341)
Log likelihood	–2,153.266	–2,312.109	–2,107.363

Note: The signs *, **, *** represent the level of significance at 10%, 5% and 1%, respectively.

Table 4 presents the parameter estimation results for the relationship between Bitcoin and the MOEX Stock Index. The GJR-GARCH (1,1)-t model demonstrates the best fit, as

evidenced by the smallest logarithmic likelihood function, making it suitable for analysing the correlation between Bitcoin and the MOEX stock index.

Based on the parameter estimation results, the estimated value of β_1 is positive but statistically insignificant, indicating that Bitcoin serves as a weak decentralised tool for the MOEX stock index in the long run. Similarly, the estimated value of β_2 is positive but again insignificant, suggesting that Bitcoin is not an effective diversification tool for the MOEX Stock Index.

Furthermore, the estimated value of β_3 is significantly negative, indicating that Bitcoin acts as a strong hedging tool for the MOEX stock index during the COVID-19 epidemic and the Russian-Ukraine crises in 2022.

Table 5 Parameter estimation results of Bitcoin and MOEX 10-year government bond index

Parameter	*GARCH-t*	*GJR-GARCH-t*	*EGARCH-t*
μ	0.066	0.032	0.067**
	(0.533)	(0.110)	(2.020)
Φ	–0.007	–0.010	–0.003
	(–0.148)	(–0.202)	(–0.0245)
α	0.040***	0.086	0.007
	(3.832)	(2.063)	(0.220)
β_0	0.820***	0.671***	0.875***
	(47.184)	(14.553)	(6,062.104)
β_1	0.076	–0.011	0.063***
	(0.028)	(–0.034)	(3.968)
β_2	0.223	0.408	0.135
	(502)	(871)	(0.575)
β_3	0.087	–0.726**	0.0132
	(0.352)	(–1.223)	(0.448)
ω	0.188	1.720***	0.038***
	(564)	(2.780)	(4.116)
Υ		0.067*	0.164***
		(1.825)	(3.816)
Sharpe	3.087	3.086***	2.501***
	(11.012)	(10.780)	(10.501)
Log likelihood	–2,111.377	–2,212.424	–2,107.363

Note: The signs *, **, *** represent the level of significance at 10%, 5% and 1%, respectively.

Table 5 displays the parameter estimation results for the relationship between Bitcoin and the MOEX ten-year government bond index. The GJR-GARCH (1,1)-t model exhibits the best fit, as indicated by the smallest logarithmic likelihood function, and is therefore chosen for analysis.

Based on the parameter estimation results, the estimated value of β_1 is negative and statistically insignificant, suggesting that Bitcoin is a weak hedging tool for the MOEX

Bond Index in the long run. The estimated value of β_2 is positive but also insignificant, indicating that Bitcoin has a weak diversification effect on the MOEX bond index. On the other hand, the estimated value of β_3 is significantly negative, indicating that Bitcoin serves as a strong hedging tool for the MOEX bond index during the crisis period.

Table 6 Parameter estimation results of Bitcoin and USD/RUB exchange rate

Parameter	*GARCH-t*	*GJRGARCH-t*	*EGARCH-t*
μ	0.103	0.042	0.104
	(0.753)	(0.155)	(1.036)
Φ	–0.003	–0.003	–0.002
	(–0.207)	(–0.263)	(–0.030)
α	0.051***	0.073***	0.013
	(3.716)	(2.720)	(0.472)
β_0	0.818***	0.642***	0.875***
	(25.454)	(12.050)	(6,141.887)
β_1	0.0281	1.015	0.102
	(0.453)	(1.438)	(0.162)
β_2	1.013	–0.316	0.821
	(0.561)	(–0.108)	(0.513)
β_3	0.447	0.038	0.562
	(255)	(0.015)	(0.091)
ω	0.216	3.541***	0.042***
	(0.658)	(2.088)	(4.373)
Υ		0.105**	158***
		(2.118)	(3.748)
Sharpe	3.082***	2.076***	1.510
	(10.642)	(11.471)	(12.237)
Log likelihood	–2,111.377	–2,212.424	–2,107.363

Note: The signs *, **, *** represent the level of significance at 10%, 5% and 1%, respectively.

Table 6 presents the parameter estimation results for the relationship between Bitcoin and the USD/RUB exchange rate. The GJR-GARCH (1,1)-t model demonstrates the best fit, as indicated by the smallest logarithmic likelihood function, and is therefore selected for analysis.

Based on the parameter estimation results, the estimated value of β_1 is positive but statistically insignificant, suggesting that in the long run, Bitcoin is a weakly decentralised tool for the USD/RUB exchange rate. The estimated value of β_2 is negative and also insignificant, indicating that Bitcoin is a weak hedging tool for the USD/RUB exchange rate prior to the epidemic. Moreover, the estimated value of β_3 is positive but not significant, indicating that Bitcoin exhibits weak hedging capabilities against the

USD/RUB exchange rate during the epidemic. It also serves as a weak diversification tool for the RUB exchange rate.

Comparing the logarithmic likelihood values from Table 3 to Table 6, it can be observed that the GJR-GARCH (1,1)-t model yields the best fit for capturing the correlation relationship between Bitcoin and the main assets in the Russian financial market. Building upon this model, the present study employs the Wald test to assess the impact of the COVID-19 epidemic and the ongoing conflict between Russia and Ukraine on Bitcoin.

Table 7 Hypothesis testing of the relationship between Bitcoin and other assets before and after the crisis

Hypothetical test	*BTC-Gold*	*BTC-Stock*	*BTC-Bond*	*BTC-USD/RUB*
H0: $B_1 = B_3$	2.506*	2.116**	2.068	0.004
H0: $B_2 = B_3$	0.051**	0.141***	0.205*	0.301

Note: The signs *, **, *** represent the level of significance at 10%, 5% and 1%, respectively.

The impact of major assets in the Russian financial market on each other is assessed using the hypotheses H0: $\beta_1 = \beta_3$ to test the equality of relationships, and H0: $\beta_2 = \beta_3$ to test the similarity of correlations before and after the crises. The results of the Wald tests are presented in Table 7. According to the significant results of the hypothesis tests in Table 7, it can be concluded that the correlation between Bitcoin and the main assets in the Russian financial market undergoes significant changes following the COVID-19 epidemic and, particularly, the ongoing conflict between Russia and Ukraine. Therefore, these crises have a notable impact on the relationship between Bitcoin and the Russian financial market.

Furthermore, our study reveals that Bitcoin performs strongly as a diversification tool for the MOEX gold and MOEX stock indices. While Bitcoin works as a weak hedging tool for the MOEX Bond Index and a weak diversification alternative financial asset for the USD/RUB exchange rate.

4.3 Risk analysis: Bitcoin vs. major assets in the Russian financial market

This study employed the Cornish-Fisher estimation method to calculate VaR and CVaR for a comprehensive risk assessment of the highlighted key financial assets such as Bitcoin, gold, equity, bonds and exchange rate. Results are compared with historical simulation and variance-covariance methods, presented in Figures 3(a) to 3(e) for VaR and Figures 4(a) to 4(d) for CVaR (refer to Appendix B for clarity). Notably, these figures illustrate time-varying VaR and CVaR results for all assets, with vertical lines marking the impact of the COVID-19 economic outbreak and the Russian-Ukraine conflict 2022. During market crises, both VaR and CVaR significantly increase, emphasising Bitcoin's robust performance in the Russian financial market. Investors are cautioned to exercise prudence during crises, considering potential reductions in Bitcoin holdings amid sharp price declines. To precisely gauge risk and mitigate losses, the study employs the GJR-GARCH (1,1)-t model, capturing information shock curves and analysing the impact of positive and negative news on volatility.

Figures 4(a) to 4(e) in Appendix showcase the VAR and CVAR results, illustrating the impact of information shocks between Bitcoin and other securities: gold spot-trading, MOEX stock index, MOEX 1-year government bond index, and USD/RUB exchange rate in the Russian financial market. Asymmetrical shocks indicate a leverage effect among market assets, with Bitcoin's sensitivity to positive news regarding gold main contract, suggesting higher volatility. Negative news, such as changes in interest rates, has a greater impact on Bitcoin than positive news, revealing a negative relationship with stock, bond, and USD/RUB exchange rate. This unique dynamic in the Russian financial market, distinct from the global market, necessitates careful portfolio setting for diversification and hedging. Negative news significantly impacts USD/RUB exchange rate compared to stock and bond suggesting a generally bearish state in the Russian financial market.

Interestingly, the gold main contract has the least impact on Bitcoin volatility, making it suitable for risk avoidance during crises, aligning with gold's hedging function. Conversely, Bitcoin strongly impacts currency volatility, making it suitable for investors with higher risk appetite. The USD/RUB exchange rate has the least impact on Bitcoin volatility, making it more suitable for risk-averse and risk-neutral investors due to its stable and low volatility. These analyses confirm a leverage effect between Bitcoin and Russian financial market assets, offering valuable guidance for investors in asset allocation decisions to manage market speculation risks.

4.4 Discussion

During economic crises, the Russian economy faces numerous challenges including economic sanctions, currency depreciation, and inflation. In response, policymakers seek alternative solutions to diversify the risks associated with the financial market. This study examines the potential role of Bitcoin as a support for investors and businesses in the Russian context. Bitcoin is considered as a hedge against traditional assets (Bouri et al., 2022), offering portfolio diversification and potential safe haven properties (Caporale et al., 2020). However, our findings indicate that investing in Bitcoin during the ongoing crisis in the Russian economy is risky due to its high price volatility and lower market liquidity. The effectiveness of Bitcoin as a safe haven may vary across different markets, as previous studies have shown mixed results (Dyhrberg, 2016b; Bouri et al., 2017; Chen et al., 2020). Additionally, the dynamics of the Russian economy may differ from others. Bitcoin's limited supply and halving events contribute to its perceived value and price dynamics. We found that Bitcoin has hedging abilities against equity, bonds, and exchange rates, but investment in gold is generally considered safer than investment in Bitcoin. The high price volatility of Bitcoin presents opportunities for speculative traders in the short run (Cheah and Fry, 2015). Studies examining the relationship between Bitcoin and stock markets have yielded mixed findings. Some research suggests a positive correlation, indicating that Bitcoin may act as a risk-on asset and move in tandem with stock market movements (Bouri et al., 2017). However, other studies indicate a weak or even negative correlation, suggesting that Bitcoin may offer diversification benefits to stock portfolios (Baur et al., 2018). During certain periods of market stress, such as the COVID-19 pandemic, temporary alignments between Bitcoin and stock prices have been observed.

Numerous studies have explored the relationship between Bitcoin and gold, considering them as alternative assets for storing value. In the context of the Russian financial market, both Bitcoin and gold can be utilised as risk-avoidance instruments. Some research suggests a positive correlation, indicating that Bitcoin and gold may act as safe-haven assets during periods of economic uncertainty (Bouri et al., 2020). However, other studies suggest a weak or insignificant correlation, highlighting differences in their underlying characteristics and investor preferences (Caporale et al., 2020). Our findings indicate that Bitcoin is a weak tool for hedging and diversifying the USD/RUB exchange rate, particularly before the onset of the epidemic. The literature presents mixed results regarding the relationship between Bitcoin and traditional foreign exchange rates. Some studies demonstrate evidence of a positive correlation, suggesting that Bitcoin behaves as a speculative investment similar to currencies. Conversely, other studies find no significant relationship, indicating that Bitcoin and traditional foreign exchange rates are largely independent of each other (Dyhrberg, 2016a).

The correlation between Bitcoin and traditional bonds has been relatively underexplored in the literature. This study aims to investigate the relationship between Bitcoin and Russian government ten-year bonds. Our findings indicate that Bitcoin exhibits a strong hedging ability against the MOEX Bond Index, particularly during crisis periods. However, it is widely recognised that Bitcoin and bonds generally have a low correlation due to their distinct characteristics. Bitcoin's decentralised and speculative nature sets it apart from the fixed income and interest-bearing features of bonds. Previous studies examining the relationship between Bitcoin and bonds have yielded mixed results (Yousaf et al., 2022). Some research suggests a positive correlation between Bitcoin and bonds, indicating that Bitcoin may exhibit similar safe-haven characteristics during times of economic uncertainty (Bouri et al., 2020). However, other studies have found weak or insignificant relationships, highlighting the unique properties and drivers of Bitcoin compared to traditional commodities (Cheah and Fry, 2015).

5 Conclusions

This paper employs three GARCH family estimation models to investigate the interaction between Bitcoin and the key assets in the Russian financial market before and after the COVID-19 epidemic and the Russian Ukraine conflict in 2022. In particular, our empirical analysis focuses on changes in correlations and risks, utilising the gold sport trading contracts, MOEX stock index, MOEX ten-years government bond index, and the exchange rate (USD/RUB) as main indicators of the Russian financial market. By employing the optimal AR-GARCG, GJR-GARCH and E-GARCH (1,1)-t model with logarithmic returns are examined for the underline securities. The motivation to examine the Russian financial market at this specific timeline as several objectives such as: the timeline for data analysis starting from January 1, 2018, to May 30, 2023, is more important with respect to economic crisis of COVID-19 and Russian Ukrainian Crisis (2022). During these crises the Russian financial market faced numbers of economic sanctions and become the centre of attention for investors around the world. In addition, Russia is major exporter country of energy, metals, and commodities, which as impact on global financial market. The world major investment companies are more concern with

Russian financial market. The selected financial assets in this study are considered as main trading assets in global trading markets.

The findings of the study exhibit strong static correlation coefficient among Bitcoin and other main financial assets as expected in the review of literature. The correlation between Bitcoin and underline assets is time varying and changes with market situation. The study found significant impact of information shocks on Russian financial market. In particular, the positive news has more effect in comparison with the effect of bad news on the underline assets. From preliminary analysis we found that Bitcoin, a strong hedging tool, and a weakly decentralised tool for the MOEX gold-sport trading contract, the MOEX stock index, the MOEX ten-years government bond index, and the USD/RUB exchange rate, respectively. The effect of negative news on Bitcoin volatility stemming from the MOEX gold is relatively small, while positive news has a greater impact. Conversely, negative news has a greater impact on Bitcoin volatility in relation to the MOEX stock index, MOEX bond index, and USD/RUB exchange rate.

Moreover, the VaR and CVaR results calculated using the Cornish-Fisher method. Which indicate that the risk in the Bitcoin market increases significantly during both crisis periods, surpassing the risks estimated by the historical simulation method and the variance-covariance method. The Cornish-Fisher method proves to be more suitable for estimating the risk of Bitcoin during crises due to its ability to account for high volatility characteristics.

In summary, the correlation between the Bitcoin returns and the major asset in the Russian financial market has significant. In addition, strong correlation is observed during the crisis investors can still adjust their asset allocation based on the impact of positive and negative news on Bitcoin market volatility to mitigate risks associated with the pandemic and the Russian Ukraine conflict. This study provides valuable insights into the correlation between Bitcoin, gold, stock, bonds, and exchange rate in Russian financial market. The results and provides considerable investment information for asset portfolio allocation and investment decision decisions during the current crisis period. The concern stack holders and trading partners are suggested to play their role and do make their efforts to hold this ongoing crisis and rescue the regional and global economy from another economic crisis. The estimation tools and methodology employed in this paper is relatively simplistic. For future research scholars can use stochastic processes and probability transitions estimation to measure the changes more deeply in dynamic correlation. Improving the methodology will enhance the accuracy of the findings and offer more constructive suggestions for investors and regulators.

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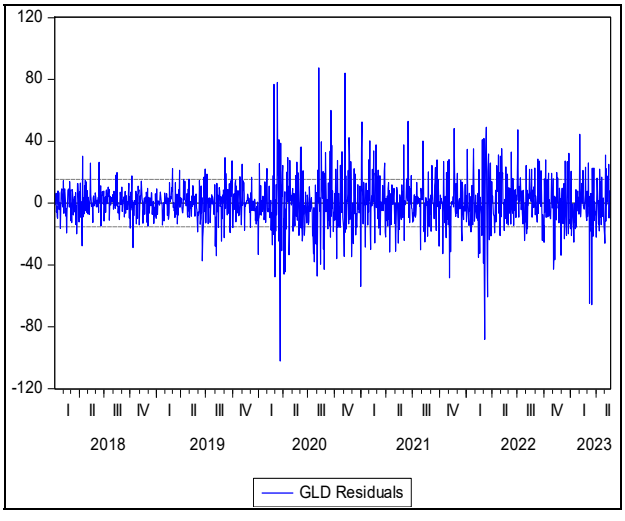
Notes

1 The MOEX Russia Index is a major stock market index that tracks the performance of the 50 largest and most liquid Russian companies from ten main economy sectors listed with Moscow Stock Exchange. It is a capitalisation-weighted composite index where the MOEX has a base value of 100. The gold prices are derived from FX and precious metals market.

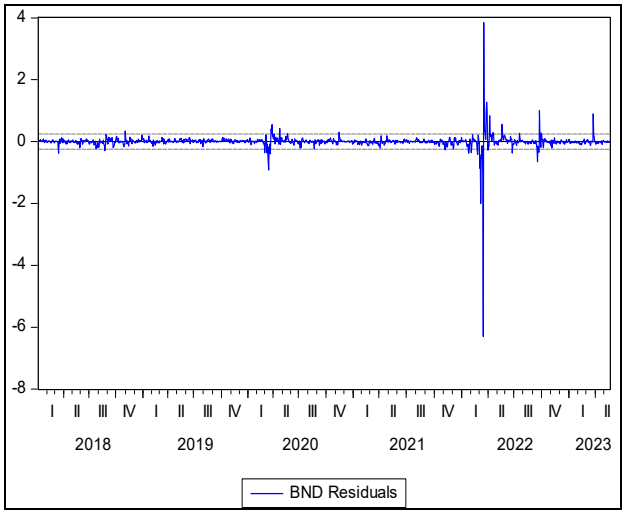
Appendix A

Figures 3(a) to 3(d) represents the key financial assets of Russian financial market where gold, bonds, equity and USD/rub exchange rate are showed from Figure 3(a) to 3(d) respectively.

Figure 3 (a) Gold-spot index response to the COVID-19 and Russia Ukraine conflict, (b) MOEX ten-year govt. bond index response to the COVID-19 and Russia Ukraine conflict, (c) MOEX stock index response to the COVID-19 and Russia Ukraine conflict, (d) Exchange rate USD/rub response to the COVID-19 and Russia Ukraine conflict (see online version for colours)



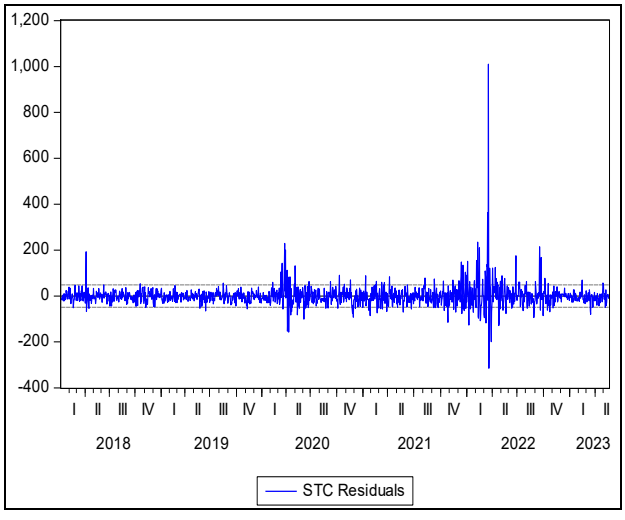
(a)



(b)

Source: Author's self-calculation

Figure 3 (a) Gold-spot index response to the COVID-19 and Russia Ukraine conflict, (b) MOEX ten-year govt. bond index response to the COVID-19 and Russia Ukraine conflict, (c) MOEX stock index response to the COVID-19 and Russia Ukraine conflict, (d) Exchange rate USD/rub response to the COVID-19 and Russia Ukraine conflict (continued) (see online version for colours)



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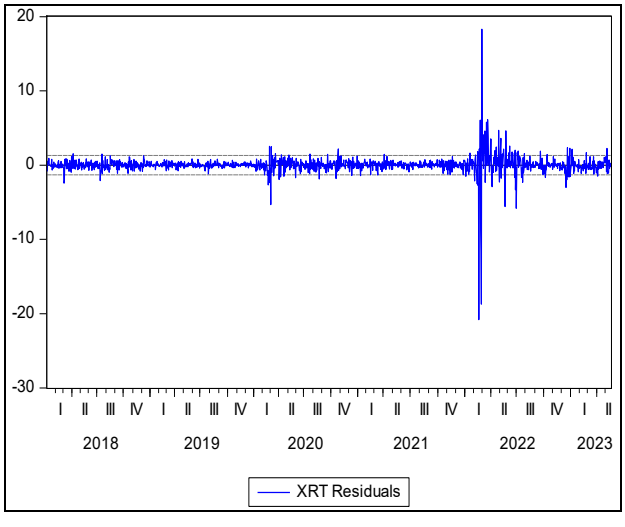


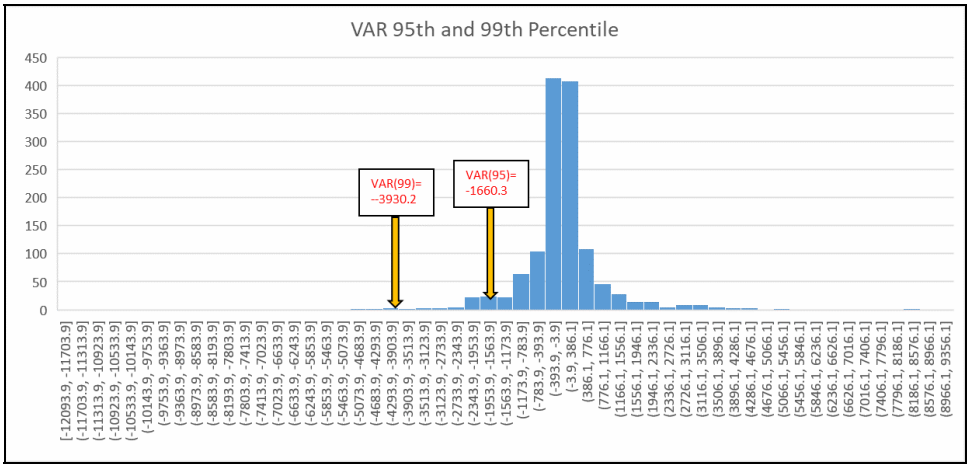
(d)

Source: Author's self-calculation

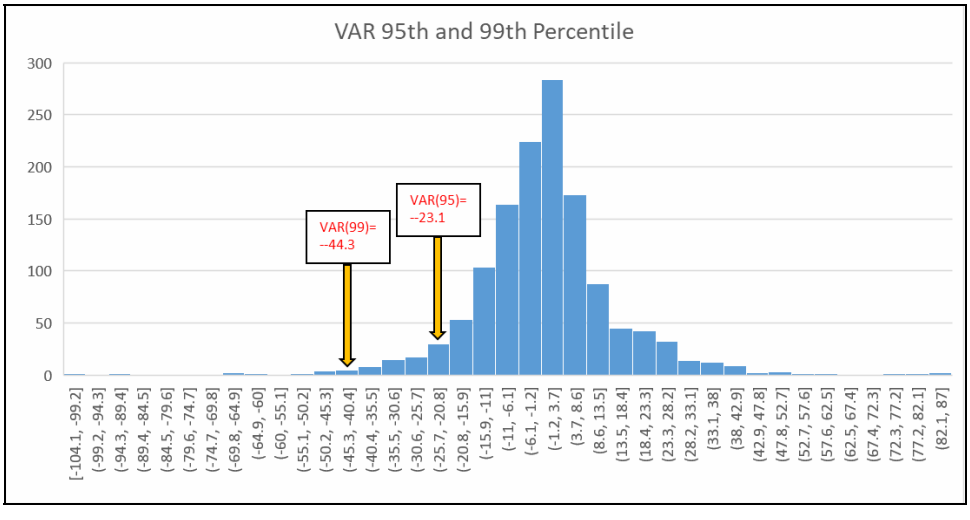
Appendix B

Figures 4(a) to 4(e) represents the VaR and CvaR for the key financial assets of Russian financial market where BTC, gold, bonds, equity and USD/rub exchange rate are showed from Figures 4(a) to 4(e) respectively.

Figure 4 (a) Bitcoin: VAR at 95% and 99% confidence level, (b) GLD: VAR at 95% and 99% confidence level, (c) STC: VAR at 95% and 99% confidence level, (d) BND: VAR at 95% and 99% confidence level, (e) XRT: VAR at 95% and 99% confidence level (see online version for colours)

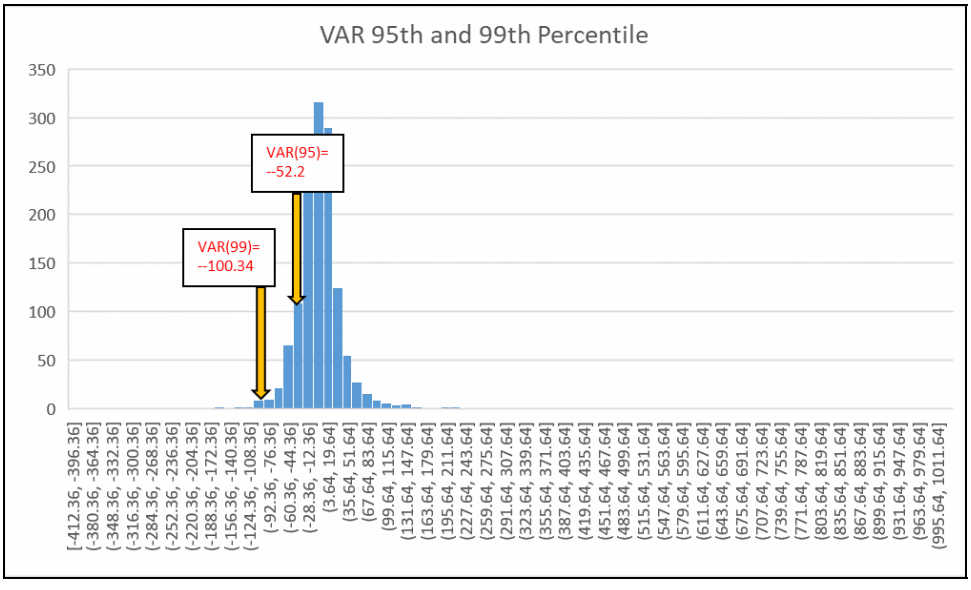


(a)



(b)

Figure 4 (a) Bitcoin: VAR at 95% and 99% confidence level, (b) GLD: VAR at 95% and 99% confidence level, (c) STC: VAR at 95% and 99% confidence level, (d) BND: VAR at 95% and 99% confidence level, (e) XRT: VAR at 95% and 99% confidence level (continued) (see online version for colours)



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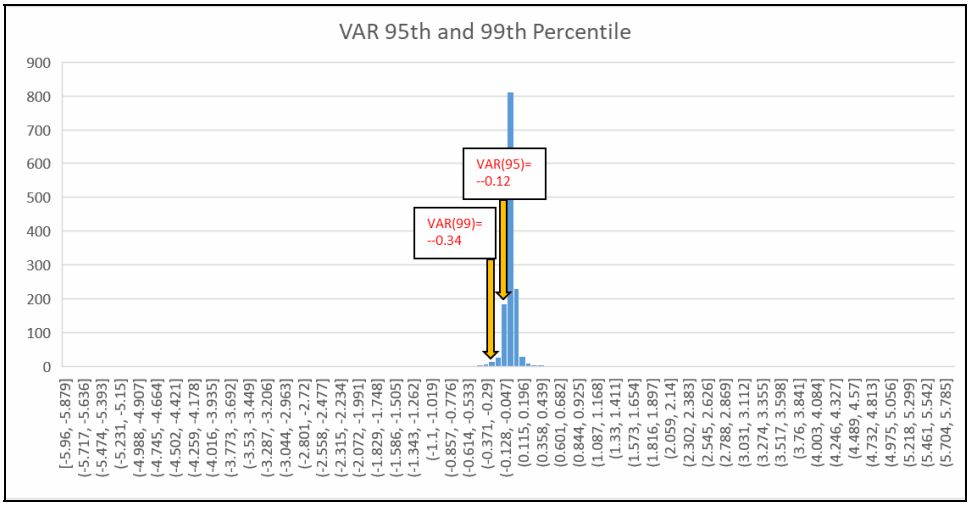
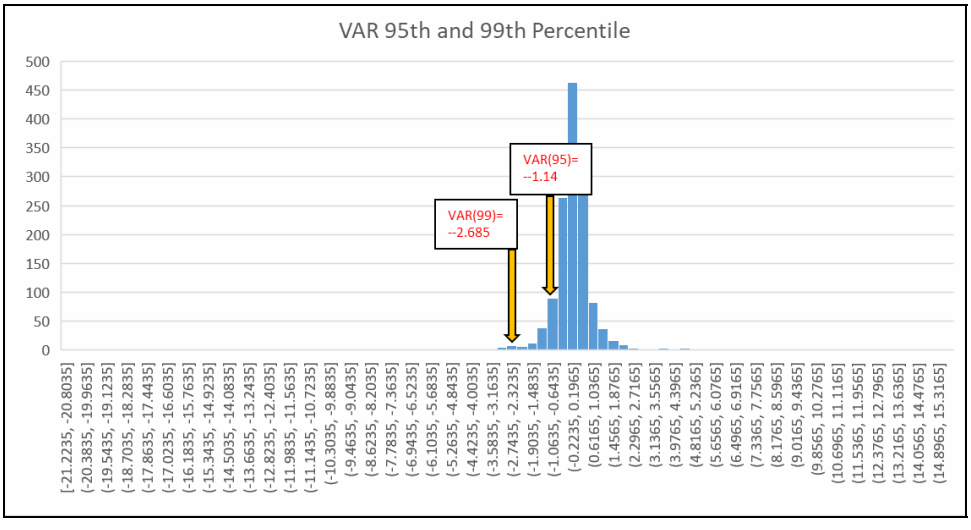


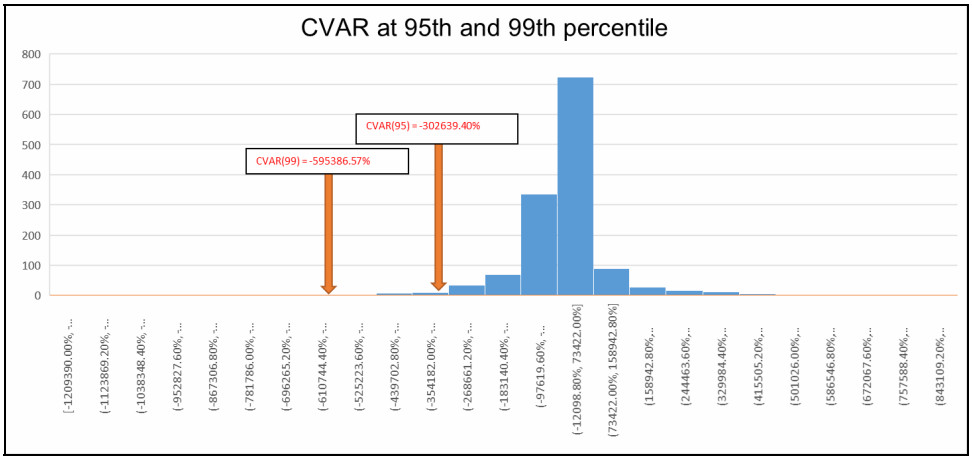
(d)

Figure 4 (a) Bitcoin: VAR at 95% and 99% confidence level, (b) GLD: VAR at 95% and 99% confidence level, (c) STC: VAR at 95% and 99% confidence level, (d) BND: VAR at 95% and 99% confidence level, (e) XRT: VAR at 95% and 99% confidence level (continued) (see online version for colours)



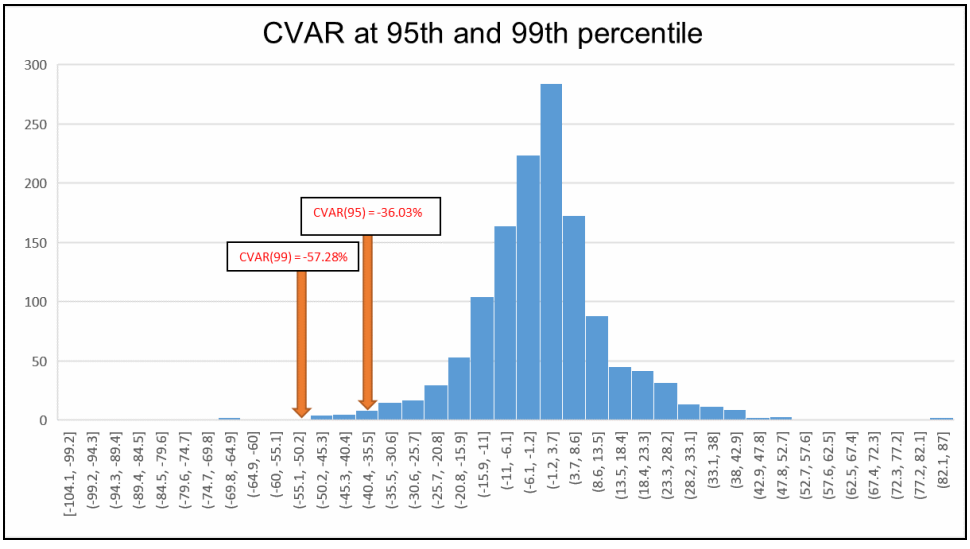
(e)

Figure 5 (a) Bicton: CVAR at 95% and 99% confidence level, (b) GLD: CVAR at 95% and 99% confidence level, (c) STC: CVAR at 95% and 99% confidence level, (d) BND: CVAR at 95% and 99% confidence level, (e) XRT: CAR at 95% and 99% confidence level (see online version for colours)

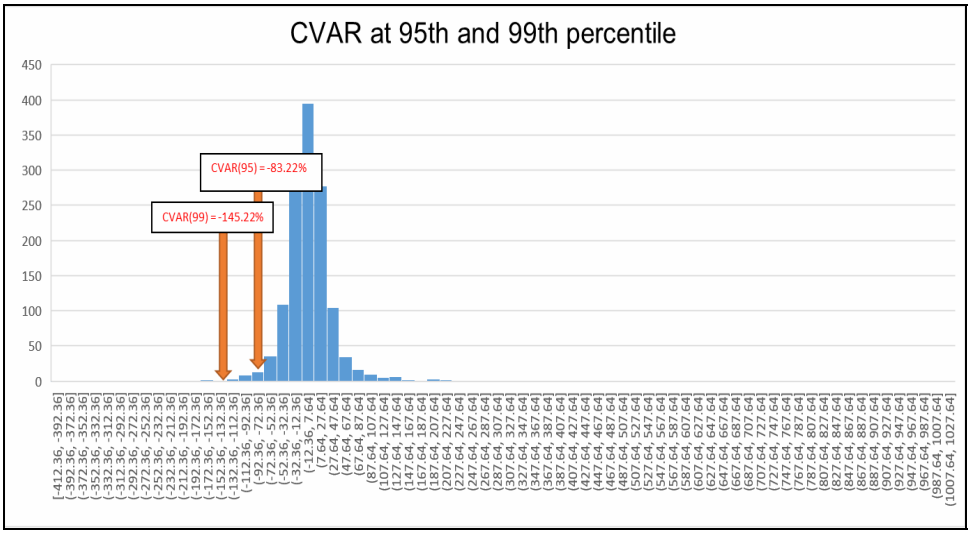


(a)

Figure 5 (a) Bicton: CVAR at 95% and 99% confidence level, (b) GLD: CVAR at 95% and 99% confidence level, (c) STC: CVAR at 95% and 99% confidence level, (d) BND: CVAR at 95% and 99% confidence level, (e) XRT: CAR at 95% and 99% confidence level (continued) (see online version for colours)

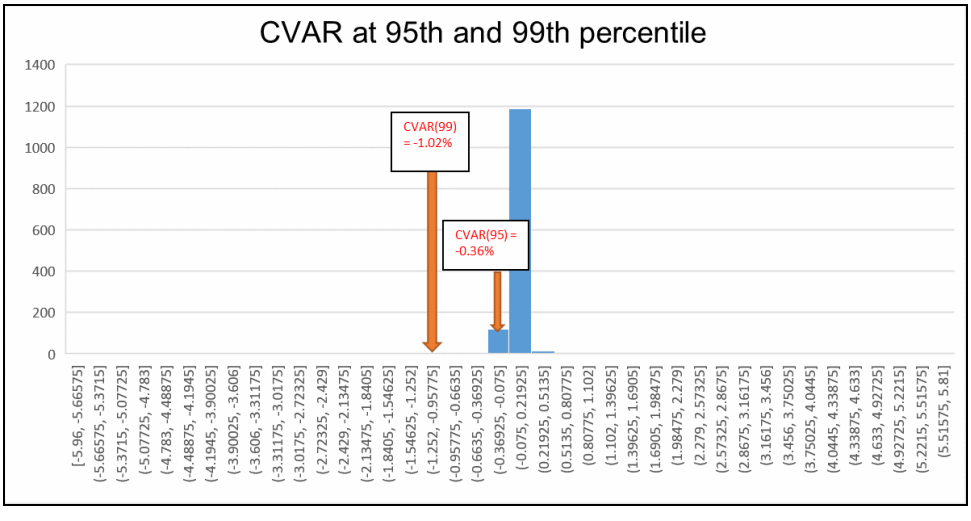


(b)



(c)

Figure 5 (a) Bicton: CVAR at 95% and 99% confidence level, (b) GLD: CVAR at 95% and 99% confidence level, (c) STC: CVAR at 95% and 99% confidence level, (d) BND: CVAR at 95% and 99% confidence level, (e) XRT: CAR at 95% and 99% confidence level (continued) (see online version for colours)



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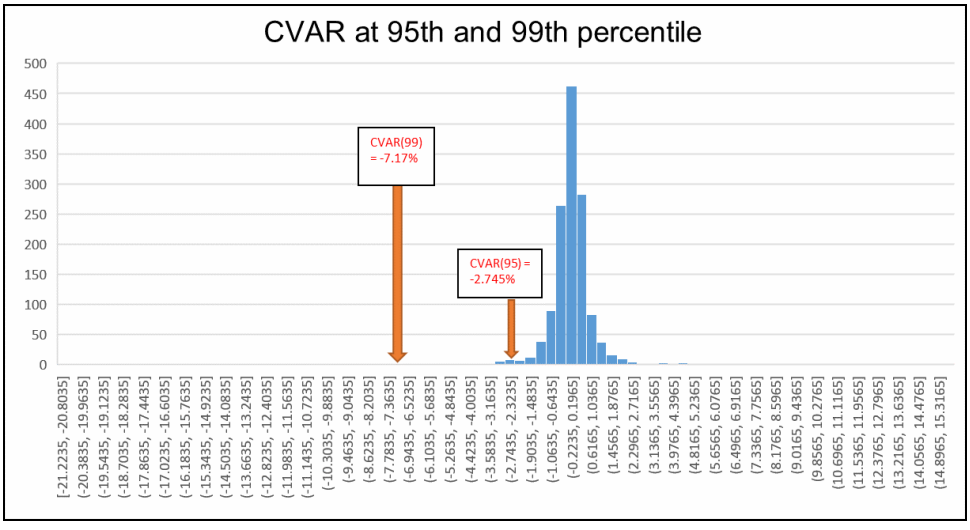

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