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Dynamic Interconnectedness and Portfolio Implications of Bitcoin, Gold, Currencies, and TASI:
A TVP-VAR Approach

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Abstract
Our study examines the safe-haven characteristics of Bitcoin, gold, TASI, JPY/USD, and CHF/USD during periods of market turbulence: the COVID-19 pandemic and the Russian invasion of Ukraine. The objective is to create robust portfolios by exploring the dynamic interrelationships among these assets, offering a comprehensive understanding of how they interact over time. Utilizing a time-varying parameter vector autoregression (TVP-VAR) model, we use four portfolio techniques–containing minimum variance, minimum correlation, minimum connectedness portfolios and Risk parity Portfolio–to estimate the Sharpe ratios and cumulative return of the portfolios. The analysis reveals a complex interplay of risk and hedging potential across different portfolio strategies. Bitcoin demonstrates high hedge effectiveness in certain contexts, particularly within the Minimum Variance Portfolio (MVP) and Risk Parity Portfolio (RPP), due to its low correlation with traditional assets. These findings provide critical information for international investors seeking to safeguard their savings during periods of economic uncertainty and unexpected global events.

Keywords
Bitcoin, Gold, Currencies, TASI, Connectedness, Hedge and safe haven, portfolios

1. Introduction
Market interconnectedness is critical in finance, shaping realized volatility and returns spillovers while influencing portfolio diversification and risk management strategies. This interconnectedness evolves dynamically, creating both challenges and opportunities for investors seeking resilient portfolios (Belkhir et al. 2024). Thus, interconnectedness between the most popular cryptocurrencies (Bitcoin) and gold carries significant consequences for market participants as influences investor decision-making (González et al. 2020; Jareño et al. 2020; Chemkha et al. 2021; Wen et al. 2022; Wang et al. 2022; Zhu et al. 2022; Zhang et al 2023). If Bitcoin exhibits a strong correlation with a financial asset like gold, investors can manage overall risk by creating a hedge portfolio that includes a short position in Bitcoin and a long position in gold. Therefore, a thorough analysis of the connection between Bitcoin, gold, currencies markets and TASI is essential for developing effective investment strategies that enhance portfolio management.

These studies indicate that no single asset is the ultimate choice for hedging and diversifying risks across multiple markets under all conditions. Our primary contributions to this study are summarized as follows. First, we extensively analyze the financial literature on safe-haven assets. Additionally, we distinguish between hedging and safe-haven functions within a portfolio. We also employ the resulting dynamic correlations to dynamically determine the optimal portfolio allocation and hedge ratio across sample periods, allowing us to analyze their hedging effectiveness and safe-haven properties among studying the association structure among gold, Bitcoin, and Saudi stock markets. This analysis facilitates the identification of new time-varying patterns that may influence the interconnectedness among commodity, cryptocurrency, and stock markets. Second, we uncover important patterns in the reactions of gold, Bitcoin, dollar, yen, and franc to crises, showing their safe-haven properties. Third, using the time-varying parameter vector autoregression (TVP-VAR) methodology and the three portfolio techniques, we evaluate the Sharpe ratios of the portfolios.

This study explores Bitcoin's role as a hedge and/or safe haven for Saudi stock markets, comparing its performance with gold and other currencies. Bitcoin, gold, TASI, JPY/USD, and CHF/USD represent unique assets with distinct characteristics. As a decentralized digital currency, Bitcoin has gained prominence as a speculative asset. As a traditional safe-haven asset, gold has maintained its role as a store of value during economic instability. The TASI offers exposure to the Saudi Arabian stock market, which is closely linked to oil prices and the regional economy. The JPY/USD and CHF/USD currency pairs are regarded as safe-haven currencies and are influenced by global risk sentiment.

The dynamic interconnectedness among these assets reflects their varying responses to macroeconomic shocks, market turbulence, and systemic risks. For instance, Bitcoin and gold have often been compared for their potential roles as alternative stores of value; nevertheless, their behaviors during crises differ significantly. Similarly, the interplay between TASI and global equities varies according to volatility in oil prices. At the same time, JPY/USD and CHF/USD stabilize forces during periods of financial distress. Understanding the hedge and safe-haven properties of these assets can help investors protect their portfolios during adverse market conditions.

This study adopts a TVP-VAR methodological framework to analyze the interconnectedness among gold, Bitcoin markets, TASI, and currencies. Using a TVP-VAR model for time-varying connectedness and various portfolio construction techniques provides critical insights into returns and volatility spillover effects. These insights are pivotal for designing resilient portfolios that can endure unforeseen market shocks. The primary objective of this study is to create robust portfolios by exploring the dynamic interrelationships among these key markets, offering a comprehensive understanding of how they interact over time. For several compelling reasons, the Saudi market is an ideal context for conducting this research. First, it is the largest market in the Middle East and North Africa region and ranks amongst the top seven markets globally, highlighting its importance as the largest economy in region. Second, the Saudi government has implemented substantial economic diversification measures in the context of Vision 2030.

This paper is organized as follows. The next section reviews the relevant literature and provides a foundation for the study. Section 3 describes the data used in the analysis and outlines the methodology. Section 4 presents the empirical results and their implications. Finally, the last section concludes the paper.

2. Literature Review

Financial asset interconnectedness has garnered significant attention in academic and professional circles. The emergence of Bitcoin as a prominent asset class alongside traditional assets, such as gold, foreign currencies, and regional stock markets, such as TASI, underscores the need to understand their dynamic relationships. Our paper aligns with two key areas of research: the protective roles of gold and Bitcoin in mitigating adverse movements in finance. Despite the diversity of cryptocurrencies, Bitcoin is the most widely adopted cryptocurrency worldwide. Considered a digital asset and supported by empirical evidence of its diversification, hedging, and safe-haven properties against other assets, Bitcoin has attracted significant attention from investors for its potential as a safe haven (Wang et al. 2019; Stensas et al. 2019; Mizerka et al. 2020; Maghyereh and Abdoh 2020; Rehman et al. 2020; Mensi et al. 2020; Mariana et al. 2021; Będowska-S´ojka and Kliber 2021). Studies have shown that leading currency pairs often exhibit spillover effects with other asset classes, including Bitcoin and gold (Antonakakis et al., 2020). Bouri et al. (2017) found that Bitcoin exhibits more unique properties than traditional assets, particularly during periods of market turmoil. Similarly, Dyhrberg (2016) positioned Bitcoin between gold and currencies in terms of hedging capabilities. However, its high volatility and speculative nature undermine its stability as a hedging instrument. Gold, which has long been valued as a safe haven, has been the subject of many studies on its relationship with emerging assets, such as Bitcoin. Many researchers have explored these two assets as hedges and safe-havens assets across various commodities and financial markets. For example, Shahzad et al. (2019) revealed a nonlinear, time-varying relationship between Bitcoin and gold that was significantly shaped by economic uncertainty and prevailing market conditions. More recent findings on Bitcoin’s effectiveness as a safe-haven asset were obtained by Maitra et al. (2022), who extended the analysis to two cryptocurrencies and eight stock market indices. They examined risk spillover dynamics and the effectiveness of hedging strategies between these asset classes. Cryptocurrencies offered limited utility for hedging stock market risks during the COVID-19 pandemic, reflecting their diminished effectiveness in mitigating portfolio volatility under heightened market stress. Al-Nassar et al. (2023), in an exploration of the hedging and safe-haven potential of various alternate investment assets, including gold, Bitcoin, oil, and the oil price volatility index (OVX), found that the optimal weights for gold were significantly higher than those of other assets, attainment a peak during the pandemic, implying that investors consider gold a flight-to-safety asset. Similarly, using a TVP-VAR model, Ashraf et al. (2023) found that bullion, especially gold (GLD), silver (SLV), and platinum (PT), were key transmitters of shocks to both the Islamic stock market and Bitcoin during the crisis periods. The spillover directions indicate that bullion assets could act as safe havens for investors during uncertain times, as evidenced by the increased demand for these assets during the COVID-19 pandemic and the Russia–Ukraine conflict. Two recent studies have expanded this analysis to include Islamic equity markets (Chkili et al. 2021; Younis et al. 2025). Chkili et al. (2021), covering the period 2010–2020, examined Bitcoin’s role as a hedge and safe haven for Islamic stock markets and compared its performance to that of gold. They found that the dynamic connection between Bitcoin and Islamic stock markets is generally minimal and often negative during major economic and political events, suggesting the Bitcoin can be a safe haven during Islamic stock market downturns. The same idea was reported by Younis et al. (2025), who examined the interconnectedness among oil, gold, Bitcoin, and GCC stock markets during recent geopolitical events. The findings indicate varying levels of market interdependence: lower connectivity during oil-related disputes and the Russia–Ukraine conflict, yet heightened interconnectedness during the COVID-19 pandemic. Portfolio estimates indicate that gold, Bitcoin, and/or oil are valuable for portfolio diversification and hedging across various equity markets under different market conditions and investment horizons. Using the TVP-VAR model, Attarzadeh et al. (2024) examined the temporal and dynamic interconnectedness between cryptocurrency, gold, energy, and stock markets from November 2013 to August 2022, emphasizing their importance for portfolio diversification. They conclude that volatility shocks are most pronounced in the crude oil market, whereas Bitcoin exhibits weak correlations with other assets during stable, noncrisis periods. Furthermore, the connection between gold and Bitcoin weakens during crises, offering critical insights for optimizing portfolios under varying market conditions.

3. Data and Methodology

3.1 Data

This study's dataset comprises a daily time series of closing prices for the TASI (Tadawul All Share Index), who represents the Saudi Arabian stock market benchmark, reflecting the overall market performance in one of the world's largest emerging economies, alongside daily closing price data for the alternative investments under investigation: gold (who serving as a proxy for precious metal investments and a traditional safe-haven asset), Bitcoin (who captures the dynamics of the leading cryptocurrency, representing digital asset market trends), the U.S. dollar, the Japanese yen, and the Swiss franc. Our data sourced from DataStream, covering the period from January 3, 2019, to September 3, 2024.
Bitcoin and gold have a positive mean, with Bitcoin's at 0.002 and gold's at 0.000, both statistically significant. This suggests that although the averages are small, they significantly differ from zero. TASI, JPY/USD, and CHF/USD have means close to zero, indicating their daily returns hover around zero on average. The variance is notably higher for Bitcoin, reflecting typical cryptocurrency volatility. In contrast, gold, TASI, JPY/USD, and CHF/USD showed near-zero variances, demonstrating relative stability.

Skewness highlights the asymmetric nature of returns. Bitcoin and TASI exhibit strong negative skewness, meaning their return distributions are skewed to the left, with losses more frequent or larger than gains. In contrast, JPY/USD and CHF/USD exhibit positive skewness, where gains are more frequent or greater. These findings are statistically significant. Excess kurtosis is observed across all assets, indicating fat tails in the return distributions, implying a greater probability of extreme returns. Bitcoin and TASI, in particular, have high kurtosis values, reflecting their increased likelihood of extreme price movements.

The Jarque–Bera test confirms that all assets deviate from normal distribution patterns. This non-normality is particularly evident in Bitcoin and TASI because of their high skewness and kurtosis. The Elliott–Rothenberg stock (ERS) test results are significant for all assets, meaning none of the return series follows a random walk, indicating stationarity. The autocorrelation analysis, measured by Q(20), shows that Bitcoin and TASI have significant autocorrelations, suggesting time-dependent return patterns. Although gold exhibits minimal autocorrelation, JPY/USD and CHF/USD pair exhibit moderate time dependence.

The squared autocorrelation ($Q^2(20)$) further reveals significant volatility persistence in all assets, especially TASI, JPY/USD, and CHF/USD, exhibiting strong ARCH or GARCH effects. Kendall correlations indicate that Bitcoin maintains low but statistically significant positive correlations with gold, TASI, JPY/USD, and CHF/USD. Gold has moderate correlations with JPY/USD and CHF/USD. TASI shows weak correlations with other assets, whereas JPY/USD and CHF/USD exhibit the strongest correlation among themselves, reflecting their similar reactions to global market conditions. In conclusion, Bitcoin is a highly volatile asset with extreme distribution characteristics and low correlations with traditional assets. Although more stable, gold correlates moderately with currencies. TASI exhibits volatility persistence and extreme movements, whereas JPY/USD and CHF/USD are interdependent.

Table 1 Descriptive Statistics

	Bitcoin	Gold	TASI	JPY USD	CHF USD
Mean	0.002*	0.000*	0.000	0.000	0.000
	(0.095)	(0.064)	(0.229)	(0.174)	(0.388)
Variance	0.002	0	0	0	0
Skewness	-1.240*	-0.396*	-1.515*	0.486*	0.346*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Ex.Kurtosis	16.764*	3.076*	13.729*	6.320*	2.383*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
JB	17555.058*	616.730*	12082.450*	2498.933*	376.403*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ERS	-9.751	-8.276	-9.835	-3.311	-8.502
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Q(20)	18.540	12.307	58.168*	14.477	26.388*
	(0.032)	(0.284)	(0.000)	(0.145)	(0.001)
Q2(20)	21.306*	127.978*	584.602*	235.956*	84.659*
	(0.010)	(0.000)	(0.000)	(0.000)	(0.000)
Kendall	Bitcoin	Gold	TASI	JPY USD	CHF USD
Bitcoin	1.000*	0.079*	0.038	0.041	0.074*

Gold	0.079*	1.000*	0.036	0.316*	0.313*
TASI	0.038	0.036	1.000*	0.005	0.048*
JPY USD	0.041	0.316*	0.005	1.000*	0.373*
CHF USD	0.074*	0.313*	0.048*	0.373*	1.000*

Figure 1 depicts the fluctuations in the performance of several financial assets, illustrating how their values change daily. Bitcoin exhibits significant spikes and drops, reflecting its high volatility, which is typical for cryptocurrencies, where sudden and considerable price movements occur daily. The magnitude of these shifts suggests a higher risk associated with Bitcoin than with other, more stable assets. In contrast, assets such as gold and CHF/USD probably demonstrate more stable return patterns. Their fluctuations are less extreme, and their returns hover closer to zero. This stability is consistent with the reputation of gold and safe-haven currencies, such as CHF/USD, which investors often use to mitigate risk during periods of economic uncertainty. The smoother lines on the figure indicate fewer extreme movements.

The relationships between certain assets, such as JPY/USD and CHF/USD, may reveal correlated movements. These currencies often behave similarly, particularly during global financial stress, and the figure might reflect this by showing aligned movements in their returns. The synchronization of these movements indicates their shared role as safe-haven assets, providing stability during times of market volatility. This figure may also capture the moments of market-wide reactions to significant economic events. Sudden spikes or drops across multiple assets could signal global events, such as the COVID-19 pandemic, the Russian–Ukraine war, the Israel–Palestine conflict, financial crises, or other geopolitical developments, which cause abrupt shifts in market sentiment. These periods of collective volatility reflect global markets' interconnectedness and the impact of significant events on various asset classes. Bitcoin's erratic and large fluctuations emphasize its high-risk, high-reward nature, whereas assets such as gold and CHF/USD offer more predictable and stable returns. Daily return patterns allow for assessing the individual behavior of assets and their interactions in response to broader market dynamics.

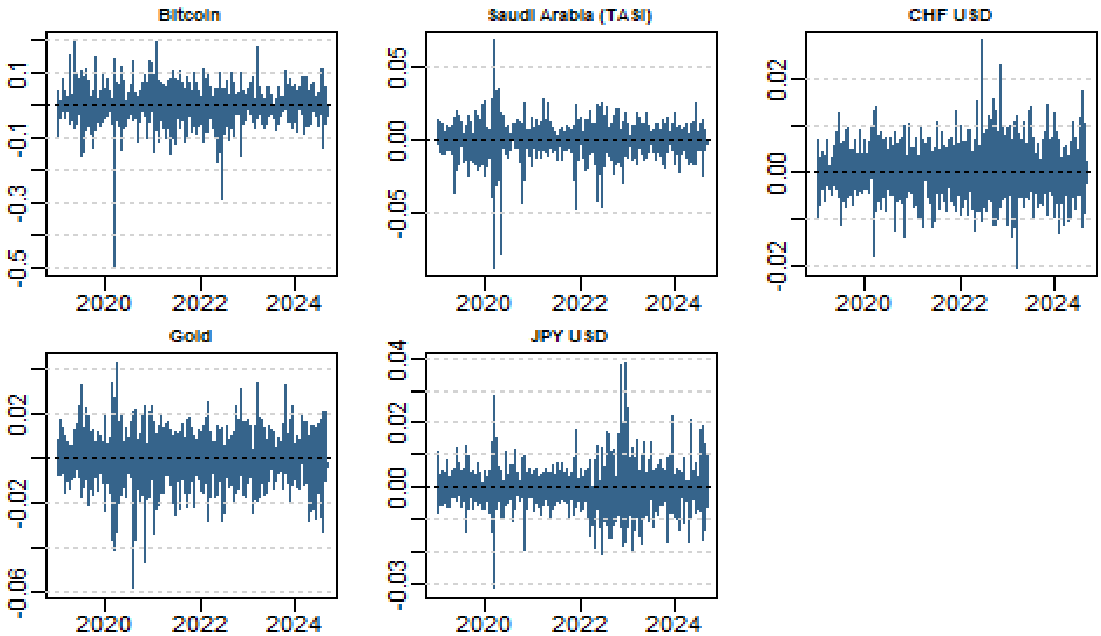

Fig. 1 Daily Returns

3.2 Empirical Methodology

The analysis was conducted in two stages. The first involves econometric modeling and interpretation of connectedness measures, and the second focuses on portfolio construction and evaluation. The empirical methodology for modeling dynamic connectedness in a system of variables involves several key steps. First, a multivariate Kalman filter TVP-VAR algorithm is implemented, which is then converted to a TVP-variance moving average (TVP-VMA)., allowing the parameters and error variances to vary over time. These time-varying parameters and error variances form the basis for the generalized impulse response functions (GIRF) and generalized forecast error variance decompositions (GFEVD). These tools help determine the extent to which variable i is influenced by other variables and how much it influences all other variables. By summing the shares of the error variance for variable i due to other variables j, the total directional connectedness FROM all others is established, indicating the influence of all other variables on variable i. Conversely, calculating the influence of variable i on all other variables j provides the total directional connectedness TO all others, derived by accumulating the effects (error variance) that variable i has on each other variable's forecast error variance. The net total directional connectedness is then obtained by subtracting the FROM measure from the TO measure (TO–FROM). Finally, the average amount of network comovement, expressed as a percentage, is summarized in the total connectedness index (TCI). The Monte Carlo simulations presented by Chatziantoniou and Gabauer (2021) and Gabauer

(2021) demonstrated that, by construction, the own variance shares are always larger than or equal to all cross-variance shares. We then analyze historical investment performance by conducting backtests on portfolios to assess the financial significance of our findings. Following Antonakaksis et al. (2021), the TVP-VAR model's estimated time-varying variance–covariance matrix is used for portfolio construction. We ensure robustness using four portfolio management approaches based on time-varying connectedness.

3.2.1 Modeling Time-Varying Connectedness Using Tvp-Var

Here, we describe the TVP-VAR model's key econometric structure. For simplicity, we present it as a first-order VAR, which our later empirical work, guided by the Bayesian information criterion, confirms as the appropriate lag order. The TVP-VAR model can be expressed as follows:

$$y_t = \emptyset_t y_{t-1} + \varepsilon_t \qquad (\varepsilon_t | F_{t-1} \sim N(0, H_t)) \tag{1}$$

$$vec(\emptyset_t) = vec\emptyset_{t-1} + \epsilon_t \qquad (\epsilon_t | F_{t-1} \sim N(0, \omega_t)) \tag{2}$$

where F_{t-1} denotes all information up to $t-1$; y_t denotes the return series; ε_t is the error variance $m \times 1$ dimensional vectors; $\emptyset_t$ and H_t are $m \times m$ dimensional matrices representing time-varying error variance and parameter variance, respectively, and indirectly accounting for volatility changes, ϵ_t and $vec(\emptyset_t)$ are $m^2 \times 1$; and ω_t is a $m^2 \times m^2$ dimensional matrix, where ϵ_t is the error term that captures the random fluctuations in the evolving VAR model parameters. The GIRF and GFEVD are calculated by first converting TVP-VAR into its TVP-VMA representation using the World representation theorem as follows:

$$z_t = \sum_{i=1}^{p} \emptyset_{it}\, z_{t-i} + \varepsilon_t \quad = \quad \sum_{j=1}^{\infty} A_{it}\, \varepsilon_{t-j} + \varepsilon_t \tag{3}$$

where zt denotes the vector of endogenous variables at time t; p denotes the order of the VAR process, indicating the number of lags considered in the model; $\emptyset_{it}$ is the coefficient matrix associated with zt; ϵt denotes the vector of errors for the VAR model; and Ait is the coefficient matrix associated with error ϵt. GIRFs, where K is the forecast horizon, are not contingent on or influenced by the structure or order of the errors. The GIRF approach effectively captures the dynamics among and between all variables j. This can be expressed as follows:

$$GIRF(\varphi_{ij,t}(K))$$
$$GIRF(K, \sqrt{H_{jj}}, F_{t-1}) = H_{jj,t}^{-1/2} A_{K,t} H_t \epsilon_t \tag{4}$$

The GFEVD then demonstrates each variable's distinct contribution to the forecast error variance of variable i, indicating the extent to which one variable, in percentage terms, influences the forecast error variance of another variable in the system. This can be expressed as follows:

$$GFED_{ij,t}(K) = \frac{\sum_{t-1}^{K-1} GIRF_{ij,t}^2}{\sum_j^m GIRF_{ij,t}^2}, \tag{5}$$
$$\sum_{j=1}^{m} GIRF_{ij,t}(K) = 1, \sum_{i,j=1}^{m} GIRF_{ij,t}(K) = m,$$

With these measures for GIRF and GFEVD at our disposal, we can effectively quantify the influence of other variables on variable i and the reciprocal influence of variable i on all others variables. In addition, we assess whether variable i has a greater impact on others than they impact it. We achieve this by using the following three metrics:

The total directional connectedness FROM all others, is computed as follows:

$$FROM_{i \leftarrow j,t} \frac{\sum_{j=1, i \neq j}^{m} GFED}{\sum_{i=1}^{m} GFED} * 100 \tag{6}$$

The influence of all other variables on variable i must be strictly below 100% because the influence of i on itself has been excluded.

The total directional connectedness TO all others is as follows:

$$TO_{i \to j,t} \frac{\sum_{j=1, i \neq j}^{m} GFED}{\sum_{j=1}^{m} GFED} * 100 \tag{7}$$

It is common practice to analyze the metrics of total system connectedness. Although these measures do not offer the same degree of detail as those described earlier, they provide a single metric that indicates whether a system's overall patterns of connectedness are weak or strong. This metric is referred to as the TCI. The Monte Carlo simulations outlined by Chatziantoniou and Gabauer (2021) and Gabauer (2021) demonstrate that the shares of variance attributable to an individual variable are always greater than or equal to the shares of variance attributable to all other variables. This implies that the TCI falls within the range of $\left[0, \frac{m-1}{m}\right]$. As we are interested in expressing the average level of network comovement as a percentage, which should fall between 0 and 1, so the following slight adjustment to the TCI is necessary:

$$Net_{i,t}(K) = TO_{i\to j,t} - FROM_{i\leftarrow j,t} \quad (8)$$

Finally, the TCI definition can be modified to obtain pairwise connectedness index (PCI) scores between variables i and j as follows:

$$TCI_t^e(K) = \frac{\sum_{i,j=1,i\neq j}^{m} Adj-GFED}{k} \quad \text{with} \quad 0 < TCI_t^e(K) < 1 \quad (9)$$

where $TCI_t^e(K)$ is the adjusted TCI for the forecast horizon K. This index measures the average amount of network comovement among variables for this time horizon. Adj-GFED represents the adjusted-generalized forecast error variance decomposition (Adj-GFEVD) between variables i and j for forecast horizon K. It quantifies variable j's contribution to the forecast error variance of variable i, adjusted for the impact of other variables in the system.

3.2.2 Portfolio Implications: Dynamic Allocation and Risk Assessment

3.2.2.1 Minimum Variance Approach

The minimum variance portfolio (MVP) approach is widely used in portfolio construction. As introduced by Markowitz (1959), this procedure creates a portfolio with the least volatility by incorporating multiple assets. The portfolio weights are determined by the following formula:

$$OW^* = \frac{[Var-Cov]_t^{-1} I}{I\,[Var-Cov]_t^{-1} I} \quad (10)$$

where OW^* denotes the portfolio weight vector; I is an m-dimensional vector of ones; and $[Var - Cov]_t^{-1}$ denotes the $m \times m$ conditional variance–covariance matrix for period t.

3.2.2.2 Minimum Connectedness Approach

Building on the concepts of these portfolio techniques, we introduce the minimum connectedness portfolio (MCoP), using pairwise connectedness indices rather than variance or correlation matrix. Minimizing interconnectedness across variables and reducing spillovers makes the portfolio less susceptible to network shocks. As a result, investment instruments that are neither influenced nor influenced by others will be assigned higher weights. This can be expressed as follows:

$$OW^* = \frac{[PWConnect]_t^{-1} I}{I\,[PWConnectCorr]_t^{-1} I} \quad (11)$$

where $[PWConnect]_t^{-1}$ denotes the PCI matrix, and I denotes the identity matrix.

3.2.2.3 Risk-Parity Approach

Following the method of Maillard et al. (2010), we employ the risk parity portfolio (RPP) approach, which allocates portfolio weights so that each asset contributes equally to the overall portfolio risk. The rationale is that a portfolio with equal risk contributions is expected to perform better and be more resilient during market downturns and economic crises. This can be formalized as the following minimization problem:

$$min \sum_{i,j=1}^{N} (OW_{it}^*(Var - Cov)OW_t^*))i - OW_{jt}^*(Var - Cov)t\, {OW_j^*}^2 \quad (12)$$

3.2.2.4 Portfolio Backtesting: Hedging Effectiveness

The Sharpe ratio and hedge effectiveness score are utilized to evaluate portfolio performance. The Sharpe ratio, also known as the reward-to-volatility ratio (Sharpe, 1966), is defined as follows:

$$SR_t = \frac{E(r_{p\,(t)})}{\sqrt{Var_t}} \quad (13)$$

where $E(r_{p\,(t)})$ denotes the daily expected portfolio return, and daily portfolio's SD. In the spirit of Ederington (1979), the hedge effectiveness is expressed as follows:

$$HE = 1 - \frac{Var(Hedg)}{Var(Unhedg)} \quad (14)$$

where Var (Hedg) denotes the variance of the portfolio returns and Var (Unhedg) denotes the variance of the unhedged asset. Hedging efficiency (HE) represents the percentage reduction in the variance of the unhedged position. The higher the HE value, the greater the risk reduction.

4. Empirical Results

4.1 Total Connectedness Using TVP-VAR

The TCI dynamics shown in Figure 2 reflect how the interconnectedness of the selected assets evolves. The TCI measures how shocks in one asset are transmitted across others assets, capturing the level of market integration or spillovers among assets. In periods with high TCI, the figure indicates that assets are strongly interconnected. Conversely, during low TCI periods, assets appear less interconnected. The TCI dynamics in Figure 2 provide insight into the changing nature of financial markets and the extent of their integration. Figure 2 shows periods of heightened connectedness, particularly during the financial market stress caused by the outbreak of the COVID-19 pandemic in 2020 and the Russian–Ukraine war in 2023, as well as periods of relative calm during 2021 and 2022, where the spillovers between the assets diminish. Overall, the TCI dynamic helps measure systemic risk and market interdependence. The visualization underscores the importance of monitoring these changes for risk management and portfolio diversification strategies.

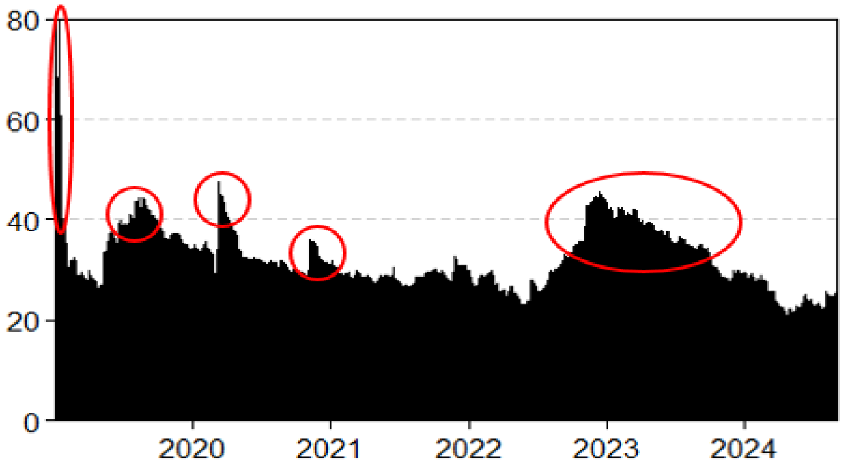

Fig. 2 Dynamic total connectedness

The data in Table 2 provide insights into how each asset is connected with others in terms of receiving and transmitting shocks. Bitcoin has the highest degree of self-connectedness at 89.24%, meaning most of its movements are driven by its own dynamics and is relatively isolated from the influence of other assets, with only 10.76% of its connectedness due to external shocks. In turn, it transmits 9.18% of the shocks to other systems, illustrating its minimal impact on other assets. Gold has lower self-connectedness (67.13%) and is more influenced by external shocks, with 32.87% of its movements attributable to other assets, particularly JPY/USD (13.36%) and CHF/USD (14.61%). Gold is also a significant transmitter of shocks, contributing 33.24% to overall connectedness. TASI is another asset with high self-connectedness (89.45%), indicating that it is largely independent of other assets, receiving only 10.55% of its movements from external sources. It transmits 8.46% of its movements, making it relatively isolated from the global market. The JPY/USD and CHF/USD pairs exhibited the highest levels of interconnectedness with other assets, with JPY/USD receiving 36.50% of its connectedness from external shocks, and CHF/USD being the largest contributor (19.31%). Similarly, 36.63% of the movements of CHF/USD were due to external shocks, with a substantial portion coming from JPY/USD (18.99%). Both currencies are strong transmitters of shocks, with JPY/USD transmitting 38.14% and CHF/USD transmitting 38.28%.

The net connectedness (NET) values show that Bitcoin (−1.57) and TASI (−2.09) are net receivers, meaning that external shocks influence them more than they influence others. In contrast, JPY/USD (1.64) and CHF/USD (1.65) are net transmitters, spreading more shocks to the system than they receive. Gold is almost balanced with a NET of 0.37, indicating that it transmits and receives shocks almost equally. In summary, Bitcoin and TASI are relatively isolated, with high self-connectedness and minimal influence on other assets. However, gold, JPY/USD, and CHF/USD are more interconnected, with JPY/USD and CHF/USD being the key transmitters of shocks in the system. The overall connectedness suggests that currencies, particularly JPY/USD and CHF/USD, play a central role in transmitting global market shocks.

Table 2 Average Dynamic Connectedness

	Bitcoin	Gold	TASI	JPY USD	CHF USD	FROM
Bitcoin	89.24	3.70	3.00	2.02	2.04	10.76
Gold	3.01	67.13	1.89	13.36	14.61	32.87
TASI	2.73	1.73	89.45	3.78	2.31	10.55
JPY USD	1.64	13.32	2.22	63.50	19.31	36.50
CHF USD	1.80	14.49	1.36	18.99	63.37	36.63
TO	9.18	33.24	8.46	38.14	38.28	127.31
Inc.Own	98.43	100.37	97.91	101.64	101.65	cTCI/TCI
NET	-1.57	0.37	-2.09	1.64	1.65	31.83/25.46
NPT	0.00	1.00	2.00	3.00	4.00	

Over time, the dynamic nature of net connectedness reveals how each asset's position shifts in response to market conditions. For instance, during the COVID-19 pandemic, Bitcoin acted as a strong net receiver of shocks, absorbing market volatility as investors turned away from risky assets. However, Bitcoin transitioned into a weak net transmitter during the Russia–Ukraine war, when it began to influence other markets, albeit with less impact than during the pandemic. The JPY/USD and CHF/USD exchange rates, consistently acted as net transmitters during both crises, driving volatility into the global market as safe-haven currencies. These results align with the empirical findings of Feder-Sempach et al. (2024), who highlighted that the yen previously served as a strong safe haven against major stock market indices and Bitcoin as a weak safe haven during times of financial distress. Notably, JPY/USD exhibited a higher amplitude, indicating a stronger role in propagating shocks, particularly during periods of uncertainty.

Traditionally considered a safe-haven asset, gold maintained its role as a net receiver in both crises, absorbing shocks rather than transmitting them. The negative connectedness underscores investors' preference for stability during market turmoil. This result aligns with the findings of Zhu et al. (2022), who observed that gold served as a hedge against the COVID-19 pandemic in the short term, whereas Bitcoin was a relatively effective asset for mitigating COVID-19 risk over the long term. Meanwhile, Ji et al. (2020) demonstrated that gold was a reliable safe-haven asset during the COVID-19 pandemic, reaffirming its irreplaceable role in preserving investment value. Finally, the TASI showed oscillating behavior during the COVID-19 pandemic, reflecting fluctuations in its connectedness and shifting between being a transmitter and receiver of shocks. By contrast, during the Russia–Ukraine war, the TASI has acted as a weak net receiver, indicating that it was impacted by external shocks but played a relatively minor role in transmitting volatility to other markets.

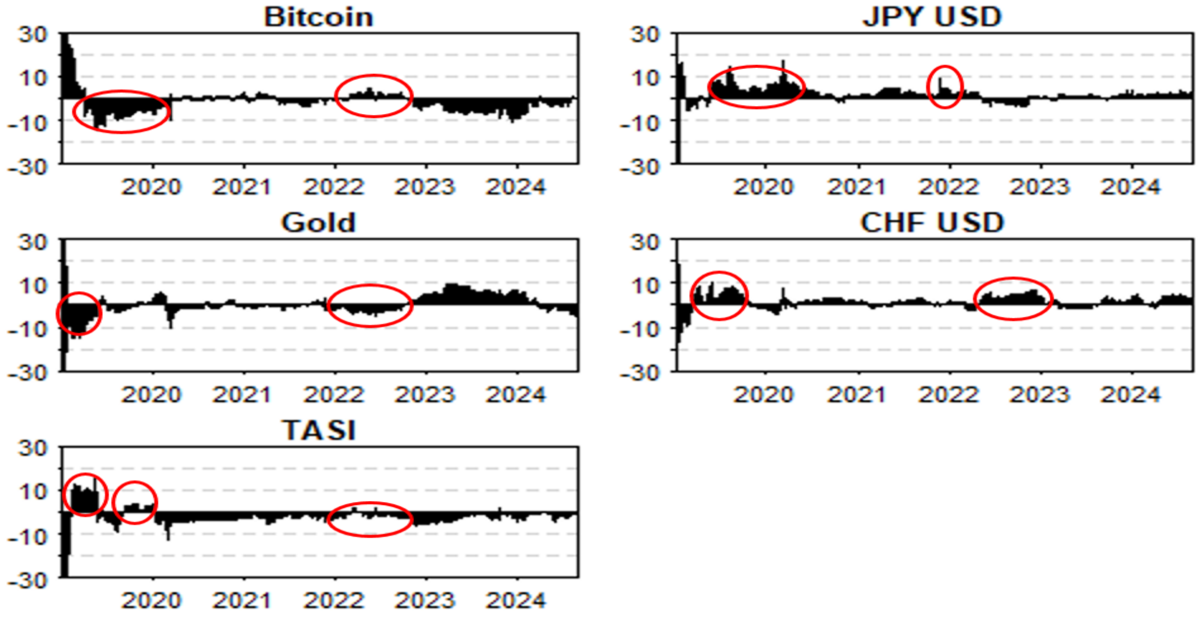

Fig. 3 Dynamic NET total Connectedness

4.2 Dynamic Portfolio Analysis

Figure 4 displays the cumulative returns of four portfolios−MVP, MCoP, minimum correlation portfolio (MCP), and RPP−from 2020 to 2024. Among them, the MCoP is the top performer, showing the highest cumulative returns throughout the period. Starting strong in 2020, despite the COVID-19 outbreak, MCoP experienced notable growth in 2021 and continues to climb steadily, mainly from mid-2022 onward, despite the Russia–Ukraine conflict. This portfolio's consistent upward trend suggests that its assets and strategy were well-aligned with the broader market conditions during this period, allowing it to deliver superior returns. Similarly, MCP follows closely behind MCoP and exhibits a significant upward trajectory. The comovement between MCP and MCoP, especially in mid-2021 and 2023, indicates that both portfolios may be exposed to similar risk factors or underlying assets. Although MCP's returns are slightly lower than RPP's, it continues to perform well, showing resilience and growth potential, particularly during market upswings in the later years of the analysis (Xu et al. 2024).

In contrast, RPP exhibits much more modest returns than MCoP and MCP. Although it shows steady growth, the overall performance remains relatively flat, with much lower cumulative returns. This portfolio appears more conservative, delivering stability over time, but it lacks the significant gains of the top-performing portfolios. Its risk-return profile suggests a focus on maintaining stability rather than aggressive growth.

In contrast, MVP has the lowest cumulative return across the period. Its returns usually hover near the baseline, indicating minimal growth potential. Although it does show some positive movement in 2023 and 2024, the gains are minimal relative to the other portfolios. MVP appears to represent a highly conservative or low-volatility strategy that sacrifices returns to reduce risk.

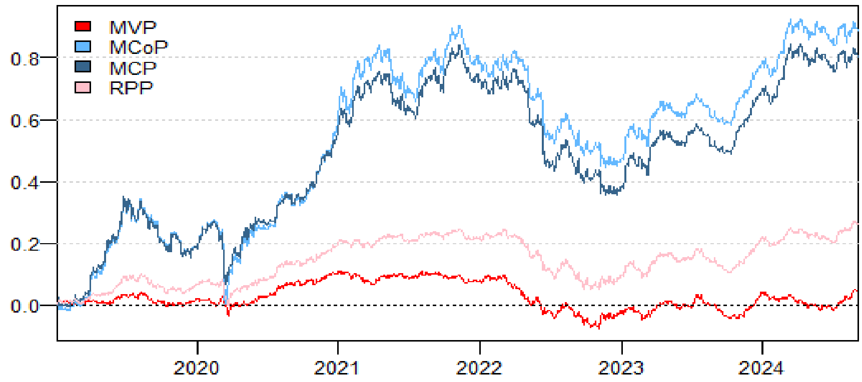

Fig. 4 Cumulative portfolio returns

The dynamic allocation of weights across portfolios—MVP, MCP, MCoP, and RPP—highlights particular investment strategies in response to changing market conditions over time. Bitcoin demonstrates fluctuating but relatively low allocations across all portfolios (Maitra et al. 2022), with the MCP and MCoP maintaining slightly higher and more stable exposures, whereas the MVP exhibits a notably conservative stance by largely avoiding Bitcoin. In contrast, gold has moderate and stable allocations, particularly within the MCoP. Consistently holding a larger share underscores its function as a hedge, consistent with the findings by Al-Nassar et al. (2023). TASI reveals significant variability in the MCoP and MCP, with notable spikes in allocation around 2022. In contrast, MVP and RPP had minimal or no exposure to TASI, reflecting different risk perceptions. Regarding currency exposure, the JPY/USD pair exhibits more dynamic allocations in MCPs and MVPs, indicating responsiveness to changing market conditions and risk tolerance. Conversely, RPP and MCoP allocate less to this currency pair, suggesting a diminished focus on currency fluctuations. CHF/USD is predominantly held in the MVP as a stabilizing asset, with frequent adjustments indicative of its hedging role. Overall, MVPs exemplify a conservative investment philosophy, prioritizing risk mitigation through increased allocations to safe-haven currencies, such as CHF/USD, and avoiding volatile assets, such as Bitcoin. In contrast, MCP and RPP balance growth and stability, exhibiting moderate exposure to Bitcoin and gold. Meanwhile, the MCoP adopts a more aggressive strategy that embraces riskier assets, such as Bitcoin and TASI, to capitalize on market opportunities. This evolving allocation strategy highlights the adaptive nature of each portfolio, effectively navigating the delicate balance between risk and return in a constantly changing market landscape.

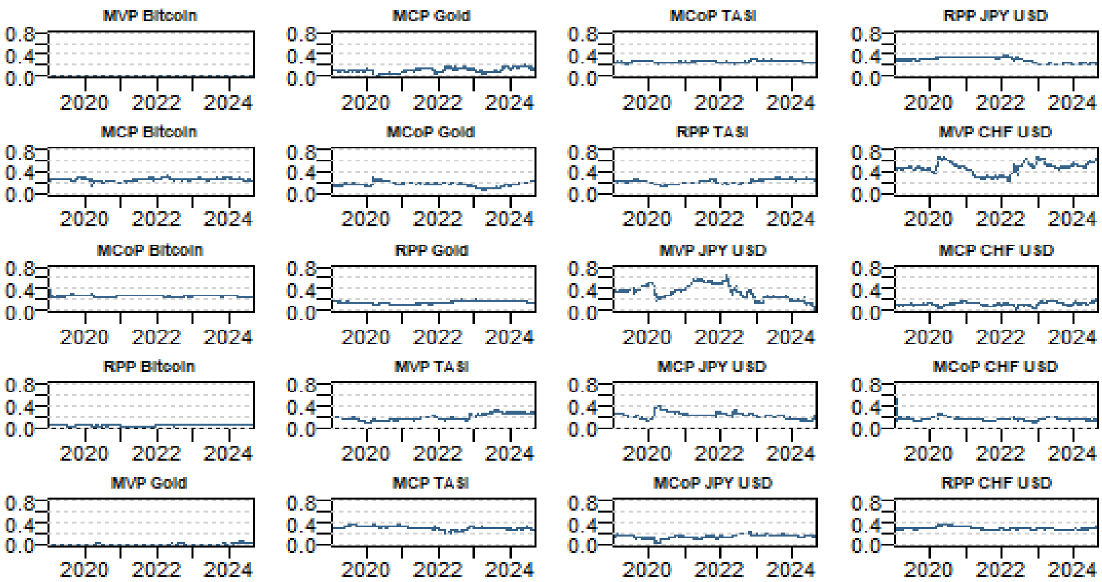

Fig. 5 Dynamic multivariate portfolio weights

Table 3 presents the dynamic multivariate portfolio weights for four distinct portfolios: minimum variance, minimum correlation, minimum connectedness, and risk parity. The MVP shows negligible exposure to Bitcoin (0.00) and minimal allocations to gold (0.01), whereas TASI (0.19), JPY/USD (0.34), and CHF/USD (0.47) represent the most significant holdings, with a focus on less volatile assets. In MCP, Bitcoin (0.25) and TASI (0.31) receive moderate allocations, indicating a strategy that leverages growth potential, alongside gold (0.11) and JPY/USD (0.22), whereas CHF/USD (0.11) is less emphasized. MCP features Bitcoin (0.26) and TASI (0.27) as key components, with gold (0.16) providing additional stability, whereas JPY/USD (0.15) and CHF/USD (0.16) have relatively lower weights. Finally, the RPP is allocated more evenly among Bitcoin (0.04), gold (0.15), TASI (0.22), JPY/USD (0.29), and CHF/USD (0.30), reflecting a balanced risk management approach across diverse assets. These portfolios illustrate various strategies in response to market conditions, balancing risk and return through adaptive weight allocations.

HE values across portfolios indicate varying degrees of risk mitigation effectiveness for the included assets. In the MVP, Bitcoin (0.99) and gold (0.84) demonstrate high HE, making them effective at minimizing risk relative to their expected returns, whereas JPY/USD (0.56) and CHF/USD (0.36) are less effective. The MCoP reveals a similar trend, with Bitcoin (0.93) serving as a robust hedge; in contrast, gold (−0.42) indicates poor hedging capability. JPY/USD (−3.00) and CHF/USD (−4.85) have significantly negative HE values, suggesting they may increase risk instead of reducing it. In the MCoP, Bitcoin (0.91) continues to excel in hedging, whereas gold (−0.75) remains ineffective. JPY/USD (−3.92) and CHF/USD (−6.20) have poor HE, confirming their risk-increasing potential[1]. Finally, the RPP highlights Bitcoin (0.99) as a critical risk mitigator, with gold (0.78) also contributing positively, whereas JPY/USD (0.37) and CHF/USD (0.08) are less effective at hedging risk. Overall, Bitcoin proved to be a consistently effective hedge across portfolios, whereas gold's efficiency varied, and currency holdings generally show diminished hedging capabilities.

Bitcoin's high hedge effectiveness in certain portfolios, such as the MVP and RPP, does not contradict its high-risk nature but rather reflects its distinctive, uncorrelated risk profile and strategic role in diversification. With minimal correlation with traditional assets, including Bitcoin in small amounts, offsets specific risks, particularly in balanced portfolios, without excessively increasing overall portfolio risk. This interplay between Bitcoin's unique market behavior and its diversification benefits explains why it is an asset with high hedge effectiveness despite its high volatility. In addition, gold's mixed role as a safe haven and hedge stems from its differing interactions with assets in various portfolio structures, where it may be an effective hedge in some contexts but offers limited or negative hedge effectiveness in MCPs or MCoPs. This variability suggests that hedging utility for gold is context dependent and influenced by portfolio design and specific asset relationships.

Table 3 Dynamic multivariate portfolio weights

	Mean	Std.Dev.	5%	95%	HE	p-value
Minimum Variance Portfolio						
Bitcoin	0.00	0.00	0.00	0.01	0.99	0.00
Gold	0.01	0.01	0.00	0.04	0.84	0.00
TASI	0.19	0.06	0.11	0.28	0.86	0.00
JPY USD	0.34	0.14	0.14	0.56	0.56	0.00
CHF USD	0.47	0.10	0.28	0.63	0.36	0.00
Minimum Correlation Portfolio						
	Mean	**Std.Dev.**	**5%**	**95%**	**HE**	**p-value**
Bitcoin	0.25	0.03	0.20	0.29	0.93	0.00
Gold	0.11	0.04	0.04	0.18	-0.42	0.00
TASI	0.31	0.03	0.25	0.36	-0.32	0.00
JPY USD	0.22	0.06	0.13	0.31	-3.00	0.00
CHF USD	0.11	0.03	0.05	0.17	-4.85	0.00
Minimum Connectedness Portfolio						
	Mean	**Std.Dev.**	**5%**	**95%**	**HE**	**p-value**
Bitcoin	0.26	0.02	0.23	0.28	0.91	0.00
Gold	0.16	0.04	0.09	0.24	-0.75	0.00
TASI	0.27	0.02	0.24	0.30	-0.62	0.00
JPY USD	0.15	0.04	0.10	0.20	-3.92	0.00
CHF USD	0.16	0.03	0.12	0.20	-6.20	0.00
Risk parity Portfolio						
	Mean	**Std.Dev.**	**5%**	**95%**	**HE**	**p-value**
Bitcoin	0.04	0.01	0.03	0.06	0.99	0.00
Gold	0.15	0.02	0.11	0.19	0.78	0.00
TASI	0.22	0.04	0.14	0.27	0.79	0.00
JPY USD	0.29	0.05	0.22	0.36	0.37	0.00
CHF USD	0.30	0.03	0.26	0.35	0.08	0.10

The Dynamic Bivariate Portfolio Hedge Ratios in Table 4 reveal the relative effectiveness of various asset combinations in hedging against risk. The hedge ratio—the amount of one asset needed to hedge against the risk of another—vary significantly among the pairs. For example, the Bitcoin/CHF USD pair exhibited the highest average hedge ratio of 0.83, indicating a strong potential for Bitcoin to mitigate the risks associated with CHF USD fluctuations. Conversely, the TASI/Bitcoin pair exhibits a very low hedge ratio of 0.02, suggesting minimal hedging effectiveness. The gold/Bitcoin

[1] In summary, the JPY/USD and CHF/USD are stable, safe-haven assets, as shown in Table 1 and Figure 1; however, their hedging effectiveness is context dependent. In MCP and MCoP, which prioritize low correlation or low connectedness, their interactions with other assets might not optimize hedge effectiveness, particularly outside of severe market downturns. This difference between their safe-haven role and their hedge effectiveness in specific portfolios explains the apparent contradiction.

pair has a hedge ratio of 0.03, whereas the gold/TASI has 0.07, showing relatively weak hedging capabilities. The gold/JPY USD and gold/CHF USD pairs show more promise, with hedge ratios of 0.79 and 0.93, respectively, indicating that gold effectively hedges against both currency fluctuations. The hedge ratios' standard deviations also exhibit considerable variability, especially in the case of Bitcoin/JPY USD (0.94) and Bitcoin/gold (0.52), suggesting differing levels of risk across these combinations. The significance levels (p-values) consistently indicate strong evidence against the null hypothesis, affirming the calculated hedge ratios' reliability. This analysis underscores Bitcoin's potential as a hedging instrument, particularly with currencies such as CHF. At the same time, gold shows promise in hedging against various assets, particularly currencies, albeit with lower ratios than Bitcoin.

Table 4 Dynamic Bivariate Portfolio Hedging Ratio

	Mean	Std.Dev.	5%	95%	HE	p-value	Return	Std.Dev	SR
Bitcoin/Gold	0.63	0.52	-0.21	1.41	0.07	0.00	0.18	0.65	0.28
Bitcoin/TASI	0.33	0.50	-0.68	0.92	0.04	0.53	0.16	0.66	0.24
Bitcoin/JPY USD	0.14	0.94	-1.60	1.38	0.03	0.00	0.23	0.66	0.34
Bitcoin/CHF USD	0.83	0.76	-0.65	1.89	0.03	0.00	0.24	0.66	0.36
Gold/Bitcoin	0.03	0.03	-0.01	0.09	0.06	0.54	0.08	0.14	0.54
Gold/TASI	0.06	0.10	-0.10	0.22	0.03	0.53	0.10	0.15	0.68
Gold/JPY USD	0.79	0.30	0.30	1.31	0.20	0.00	0.16	0.13	1.23
Gold/CHF USD	0.93	0.23	0.56	1.31	0.21	0.00	0.08	0.13	0.63
TASI/Bitcoin	0.02	0.03	-0.03	0.06	0.04	0.54	0.06	0.15	0.40
TASI/Gold	0.07	0.11	-0.12	0.24	0.02	0.00	0.06	0.15	0.41
TASI/JPY USD	-0.27	0.36	-1.05	0.12	0.07	0.00	0.06	0.15	0.42
TASI/CHF USD	-0.11	0.36	-0.83	0.32	0.03	0.00	0.06	0.15	0.43
JPY USD/Bitcoin	0.01	0.02	-0.02	0.05	0.04	0.54	-0.06	0.09	-0.65
JPY USD/Gold	0.26	0.13	0.09	0.52	0.23	0.00	-0.08	0.08	-1.06
JPY USD/TASI	-0.04	0.07	-0.14	0.09	0.05	0.53	-0.05	0.09	-0.54
JPY USD/CHF USD	0.62	0.12	0.49	0.86	0.33	0.00	-0.07	0.07	-0.95
CHF USD/Bitcoin	0.01	0.01	0.00	0.04	0.03	0.54	0.02	0.07	0.26
CHF USD/Gold	0.24	0.09	0.09	0.40	0.23	0.00	0.00	0.06	-0.06
CHF USD/TASI	0.00	0.06	-0.07	0.12	0.03	0.53	0.03	0.07	0.38
CHF USD/JPY USD	0.48	0.10	0.37	0.64	0.33	0.00	0.05	0.06	0.84

4.3 Dynamic Backtesting Portfolios: Daily Sharpe Ratio

The MVP portfolio, aiming to minimize volatility, would probably assign heavier weights to stable assets, such as gold, JPY/USD, and CHF/USD, whereas limiting exposure to more volatile assets, such as Bitcoin and TASI. The daily Sharpe ratio for MVP reflects this risk-averse strategy, resulting in fewer sharp fluctuations and more stable performance over time. Although the portfolio might occasionally experience minor spikes due to Bitcoin or TASI movements, the risk-adjusted returns would generally remain consistent. The MVP's primary focus on reducing variance ensures that even during volatile market periods, the Sharpe ratio will likely avoid extreme swings and maintain a moderate and steady performance.

Each asset's risk contribution is balanced in RPP, meaning that riskier assets, such as Bitcoin and TASI, would have lower allocations. In contrast, more stable assets, such as gold, JPY/USD, and CHF/USD, would hold more weight. The daily Sharpe ratio for this portfolio would exhibit moderate volatility because the risk is evenly distributed. During periods of strong performance for Bitcoin or TASI, the Sharpe ratio would experience noticeable spikes, but the stability of the safer assets would temper these. Similarly, during periods of market stress, the safe-haven currencies (JPY/USD and CHF/USD) would cushion the portfolio, causing the Sharpe ratio to remain positive or relatively stable. Overall, the RPP would exhibit balanced risk-adjusted returns with occasional upward or downward movements driven by Bitcoin and TASI.

MCP focuses on selecting assets with the lowest correlations and aims to reduce overall risk by diversifying the portfolio across uncorrelated assets. As a result, the daily Sharpe ratio for MCP is likely to be more volatile than that of MVP and RPP. Bitcoin, TASI, and other low-correlation assets may experience significant and sudden price movements. Although a portfolio's structure should theoretically reduce risk through diversification, uncorrelated assets could still cause sharp fluctuations in the Sharpe ratio, particularly when Bitcoin or TASI experiences rapid gains or losses. During market instability, a portfolio may suffer temporary dips in its Sharpe ratio as uncorrelated assets move unpredictably in the reaction to different market forces.

Unlike MCP, MCoP maximizes correlations among assets, resulting in smoother, more synchronized portfolio movements. The daily Sharpe ratio for MCoP would likely exhibit fewer dramatic fluctuations than MCP because the portfolio's assets tend to move in the same direction. This higher correlation could result in steady, moderate gains when markets perform well but also in sharper downturns during market corrections or periods of stress. The correlation-driven structure of a portfolio might amplify positive and negative outcomes in terms of risk-adjusted returns. However, the synchronized behavior of the assets would generally lead to a smoother Sharpe ratio profile, with less extreme spikes or dips than portfolios with uncorrelated assets. Overall, MVP and RPP focus on stability and balanced risk, whereas MCP and MCoP involve contrasting approaches to diversification, resulting in more volatile risk-adjusted returns.

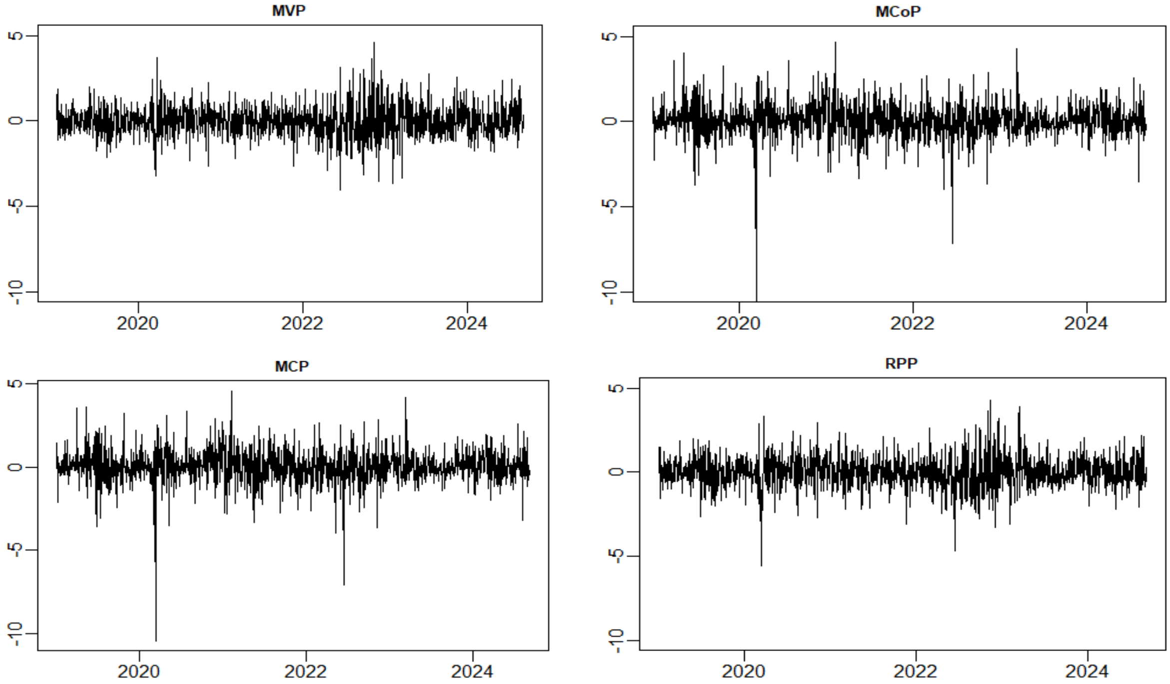

Fig. 7 Daily Sharpe Ratio

5. Conclusion

This article examined the safe-haven properties of Bitcoin, Gold, TASI, and currencies from 2020 to 2024 during significant events, involving the COVID-19 crisis and Russia's invasion of Ukraine. Bitcoin demonstrates high hedge effectiveness in certain contexts, particularly within the Minimum Variance Portfolio and Risk Parity Portfolio, due to its low correlation with traditional assets. This diversification benefit allows Bitcoin to serve as a unique hedge when weighted appropriately, offsetting specific risks without overwhelming the portfolio's stability. Gold consistently plays a stabilizing role but exhibits mixed hedging performance, with high effectiveness in risk-averse portfolios and diminishing utility in portfolios like the Minimum Correlation Portfolio and Minimum Connectedness Portfolio, where its correlation with other assets impacts its protective capacity. Safe-haven currencies (JPY/USD and CHF/USD) show robust interdependence, making them key shock transmitters during global financial stress. However, their hedge effectiveness is limited in correlation-focused portfolios, underscoring their conditional utility as hedges. Our results are practical for investors exploring for the effective safe-haven assets among gold, bitcoin, and currencies to hedge against financial turmoil in global stock markets.

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Declaration of Conflict

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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