From Receiver to Network Hub? A Time-Frequency Study of Gold's Volatility Connectedness in the Russia-Ukraine War and the 2024-2025 Price Surge

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Abstract: This paper investigates how the Russia-Ukraine war and the unprecedented 2024-2025 precious-metal price rally reshaped the volatility connectedness among gold, silver, US equities, bonds, oil, the US dollar index, and Bitcoin. Using daily data from 2018-2025, it combines the Diebold-Yilmaz time-domain framework with the Baruník-Křehlík frequency-domain approach to measure total, directional and frequency-specific spillovers in annualized volatilities across pre-war and post-war subsamples. The findings show a marked rise in aggregate connectedness after the invasion and a shift toward shorter-horizon spillovers, indicating faster and more reactive risk transmission. Gold evolves from a clear long-term net receiver of volatility shocks to a near-neutral, more tightly integrated node, while silver turns from net receiver to net transmitter, and US equities swap roles from a net receiver to a net transmitter of long-run shocks. These regime shifts suggest that gold's traditional hedge and safe-haven functions have become more state-dependent and less reliable under prolonged geopolitical stress. The results underscore the need for portfolio strategies and policy monitoring that explicitly account for time- and frequency-varying connectedness in multi-asset volatility networks.

Keywords: Russia-Ukraine war; gold; volatility connectedness; spillovers; safe haven; frequency-domain analysis.

1. INTRODUCTION

The Russia-Ukraine war, which began with the full-scale invasion on February 24, 2022, triggered a sharp repricing of risk across global financial markets with particularly pronounced effects on equities and commodities. Crude oil prices rose by more than 50% in the first half of 2022, reflecting severe supply disruptions associated with the conflict. Major equity indexes such as the MSCI World, S&P 500, and Euro Stoxx 50 recorded broad-based declines of roughly 20% over the same period. In contrast, gold fell by only about 2%, a comparatively muted response that underscored its continued perception as a defensive asset in the immediate aftermath of the invasion.

Following this initial adjustment, gold traded within a relatively narrow range through the remainder of 2022 and much of 2023 before embarking on an explosive rally during 2024-2025, with prices ultimately more than doubling. Over the same period, silver prices more than tripled, pushing both metals to record or near-record levels. This extraordinary appreciation coincided with a pronounced shift in the relationship between precious metals and equities. In 2024, the correlations of gold with the S&P 500 reached 0.1800 for returns and 0.3070 for annualized volatilities (Table 2), marking a clear departure from the traditional negative co-movement pattern. This evidence suggests that precious metals and stocks were increasingly driven by common forces such as abundant liquidity and heightened macro-financial uncertainty, rather than by traditional safe-haven behaviour in which gold offsets equity losses during periods of market stress.

Several stylized facts motivate a reassessment of gold's function in contemporary portfolios. First, the Russia-Ukraine conflict generated an immediate surge in volatility across gold and silver markets, with recent evidence pointing to rapid cross-market transmission of war-related shocks. Second, the sharp rally in gold and silver prices over 2024-2025, which sharply departs from historical patterns and outperforms most major assets, strengthens doubts about gold as a simple hedge and instead aligns it more with risk-on behaviour alongside equities and other cyclical assets. Third, the growing tendency for gold and silver to move in tandem with equities points to a possible structural change in their linkages with risk assets, raising doubts about their ability to provide reliable protection during prolonged geopolitical turmoil.

The emerging empirical literature has begun to document how gold and equities behaved around the onset of the Russia-Ukraine war. However, most existing studies were conducted early in the conflict and therefore do not incorporate the unprecedented 2024-2025 surge in precious-metal prices that is likely to have materially altered spillover patterns between gold, silver and other asset classes. Only a limited number of contributions examine gold's hedging and safe haven properties within a comprehensive connectedness framework that jointly accounts for geopolitical risk, financial instability and multiple markets, leaving open important questions regarding how war-induced uncertainty has reshaped the direction and magnitude of spillovers across assets.

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Against this backdrop, several questions remain unanswered and form the core motivation of this study. How does war-related uncertainty interact with financial instability to shape the dynamic connectedness among gold, silver, equity and other key markets, and what does this imply for portfolio construction and risk management? Given that gold prices have more than doubled and silver prices have more than tripled since the onset of the conflict, has gold's role in portfolio management fundamentally changed? Do gold's hedging and safe-haven properties still hold under extreme and prolonged geopolitical stress, or have they been weakened by the emergence of positive correlations with equities and other risky assets?

Addressing these questions is crucial for investors and policymakers seeking to judge whether gold continues to enhance diversification and downside protection when geopolitical risks are persistent rather than transitory. Our study contributes to the literature on safe havens and spillovers by providing an updated, high-frequency analysis that spans the full Russia-Ukraine conflict period and explicitly incorporates the recent explosive rally in gold and silver prices. Using daily data over an eight-year window from January 2018 to December 2025, the sample is divided into a pre-war period (January 2, 2018 - February 23, 2022) and a post-war period (February 24, 2022 - December 31, 2025), allowing for a systematic comparison of volatility connectedness patterns before and after the invasion and yielding nearly four years of post-war observations for robust inference. Within this framework, the study examines how gold's volatility connectedness with major asset classes have evolved, whether gold and silver act as net transmitters or receivers of shocks, and the extent to which their changing roles modify the strategic function of precious metals within diversified portfolios during sustained geopolitical turmoil.

The rest of the paper is organized as follows. Section 2 presents a summary of the literature review. Section 3 discusses the data and the measurement methods employed. Section 4 explains the methodology. Section 5 reports and interprets the empirical results. Section 6 concludes.

2. LITERATURE REVIEW

A substantial literature has examined the role of gold in multi-asset portfolios, typically distinguishing between its hedging and safe-haven properties. According to Baur and Lucey (2010), a hedge is a security that is uncorrelated or negatively correlated with stocks or bonds in normal times, while a safe haven remains uncorrelated with these assets during market turmoil. Baur and McDermott (2010) further differentiated between strong and weak safe havens, defining the former as assets that are negatively correlated with the market during periods of stress and the latter as assets that exhibit zero correlation in such periods. Within this framework, a large body of empirical work suggested that gold could act as both a hedge and a safe haven. For equity markets, Baur and McDermott (2010) showed that gold hedged major European and US stock indices in tranquil conditions and served as a safe haven during extreme downturns, while Beckmann *et al.* (2015) reached similar conclusions using a longer sample from 1970 to 2012. Liu *et al.* (2016) found that gold offered protection during stock-market crashes in most countries, and Wanat *et al.* (2016) documented hedging benefits for the S&P 500 over 1995-2015, whereas Smirnova (2016) emphasized gold's role as both a safe haven and a diversifier. Awartani *et al*. (2016) recommended investors to use gold and precious metals for protection of portfolio during oil shocks. Iqbal (2017) showed that gold serves as a safe haven against Pakistan's depreciating local currency using daily data, and provided similarly strong hedging and safe-haven benefits against currency risk in India. Beyond equities, Madani and Ftiti (2021) reported that gold provided strong protection against exchange-rate movements, and Wang *et al*. (2021) showed that although gold did not reliably hedge short-term currency risk, it did mitigate long-run depreciation, reinforcing its interpretation as a long-horizon safe haven in foreign-exchange markets.

Some recent post-2020 work has challenged the idea that gold still works as a reliable hedge and safe haven, particularly after COVID-19. Several studies argue that gold no longer behaved as a consistently effective hedge or safe haven, especially when measured against modern equity-market risk. Faraj et al. (2025) analyzed more than three decades of data and found that the historically negative correlation between gold and equities during crises turned positive around 2005, implying that gold increasingly comoved with stocks even in stress episodes and thus offered less diversification. Echaust and Just (2022) compared the 2007-2009 global financial crisis with the 2019-2020 pandemic and found that gold displayed safe-haven characteristics during the former but not during COVID-19. Cheng *et al.* (2025) showed that gold hedged US stocks and bonds before the pandemic but largely lost this function afterward, while Bitcoin occasionally took over part of the risk-mitigation role. Kaczmarek *et al.* (2022) concluded that long-term Treasury bonds, rather than gold or other commodities, were the only assets that consistently qualified as genuine safe havens in terms of improving out-of-sample portfolio performance in stressed conditions. Li and Liu (2026) showed that the spot gold market displays pronounced volatility clustering, underscoring the heightened sensitivity of gold assets under conditions of elevated uncertainty. Taken together, these post-2020 studies suggested that gold's traditional protective role had weakened and cautioned against treating it as a uniformly effective hedge in contemporary markets.

In parallel, an extensive literature used connectedness and spillover methods to analyze how gold interacted with other asset classes in a dynamic and multivariate setting. The connectedness framework of Diebold and Yilmaz (2012, 2014) and the frequency-domain extension of Baruník and Křehlík (2018) were particularly influential in this respect. The Diebold-Yilmaz approach employed generalized forecast-error variance decompositions from VAR models to quantify time-varying total, directional and net spillovers among assets, including gold, equities and commodities. Applying this framework, Elsayed *et al.* (2022) and Zhang *et al.* (2023) reported that gold tended to behave as a net receiver of spillovers, while Hung and Vo (2021) identified a regime shift in which gold switched from being a net transmitter before COVID-19 to a net receiver during the pandemic. Balcilar *et al.* (2021) found that over 1986-2018 gold often acted as a net transmitter of return spillovers in a system including the S&P 500 and crude oil, underscoring that gold's role was time-varying and sensitive to the sample period. Studies using the Baruník-Křehlík frequency-connectedness framework, such as Li *et al.* (2021) and Hoque *et al.* (2023), showed that spillovers involving gold were stronger at higher frequencies and that the relative importance of gold as a transmitter or receiver could differ between the short and long run. More recent work extended these analyses to include cryptocurrencies and financial-stress indices, highlighting complex, state-dependent spillover patterns between gold, Bitcoin and systemic-risk indicators.

Empirical research directly addressing the Russia-Ukraine war is still relatively limited but rapidly expanding. Izzeldin et al. (2023) documented a sharp increase in volatility and cross-market linkages in global equity and commodity markets immediately following the invasion, suggesting that war-related shocks were swiftly incorporated into prices across multiple asset classes, including gold. Shahzad et al. (2023) found that the total connectedness index among geopolitical risk, financial instability and precious-metal markets rose significantly during the conflict, while Kayral et al. (2025) reported that gold retained effective hedge and diversification properties during both COVID-19 and the Russia-Ukraine war, often outperforming Bitcoin in hedging efficiency. Biswas et al. (2024) found the increase in connectedness among the assets during the period of Russia-Ukraine war. Aslam (2025) showed that portfolios combining gold and silver with equities could reduce volatility and enhance returns across the global financial crisis, COVID-19 and the Russia-Ukraine episode. Lamine, A. (2025) found that U.S. stock market index acted predominantly as a net transmitter of shocks during the Russian invasion of Ukraine. Naifar, N. (2025) reported the total connectedness of sovereign credit risks was decreased during the Russia-Ukraine war and suggested a decoupling trend among countries. Nevertheless, most of these studies focused on the early phase of the conflict and did not incorporate the dramatic 2024-2025 surge in gold prices, nor did they provide a comprehensive frequency-domain analysis of connectedness that jointly accounted for war-related uncertainty, financial instability and multiple asset classes.

The existing literature reveals several gaps that motivated the present study. Much of the evidence on gold's hedging and safe-haven properties was based on pre-COVID or early-pandemic samples that excluded the full Russia-Ukraine conflict and its aftermath, particularly the recent explosive rally in gold and silver prices. Although some recent research has questioned the robustness of gold's traditional safe-haven status, relatively few studies have embedded these insights in a unified connectedness framework that jointly considers a broad spectrum of asset classes. The emerging literature on the Russia-Ukraine war, while expanding, has so far focused mainly on the immediate post-invasion period, documenting increases in volatility and tighter cross-market linkages but offering only preliminary evidence on gold's connectedness with other asset classes. Crucially, existing contributions do not incorporate the unprecedented 2024-2025 price surge — during which gold more than doubled — into a single framework that links geopolitical risk to the behaviour of precious metals. As a result, important questions remain unresolved: whether gold's spillover role has fundamentally changed, whether its hedging and safe-haven characteristics have persisted under prolonged and extreme geopolitical stress, and how war-induced uncertainty has interacted with financial instability to reshape the dynamic connectedness across markets. Addressing these issues requires an updated, high-frequency analysis spanning the full Russia-Ukraine conflict period and explicitly capturing the recent explosive rally in gold, thereby filling a critical gap in understanding gold's evolving behaviour and its strategic function within diversified portfolios under sustained geopolitical turmoil.

3. DATA AND MEASURES

This study uses daily financial market data over an eight-year window from January 2018 to December 2025, which is divided into a pre-war period (January 2, 2018 - February 23, 2022) and a post-war period (February 24, 2022 - December 31, 2025) with 1,031 and 956 observations, respectively. This split enables a direct comparison of volatility dynamics before and after the outbreak of the Russia-Ukraine war and ensures sufficiently long subsamples for robust estimation.

The asset universe comprises seven key markets: COMEX gold futures (GC), COMEX silver futures (SI), the S&P 500 Index (SPX), the US 10-year Treasury yield (US10Y), NYMEX WTI crude oil futures (WTI), the US Dollar Index (DXY) and Bitcoin futures (BTC). For each series, daily open, high, low, and close prices are sourced from the Wind database and consolidated into a consistent daily panel. Daily logarithmic returns are calculated as:

$$r_{i,t} = ln(\frac{P_{i,t}}{P_{i,t-1}}) \tag{1}$$

where $P_{i,t}$ denotes the daily closing price of asset i on trading day t. Volatility is measured using daily high-low price ranges, following the methodology of Parkinson (1980) and Diebold and Yilmaz (2012, 2014):

$$\widetilde{\sigma_{i,t}^2} = 0.361\ [\ \ln(P_{i,t}^{max}) - \ln(P_{i,t}^{min})\ ]^2 \tag{2}$$

where P_{it}^{max} and P_{it}^{min} are the daily highest and lowest prices of market *i* on day *t*. The daily variance is converted into annualized volatility by

$$\widehat{\sigma_{i,t}} = 100\sqrt{365\widetilde{\sigma_{i,t}^2}} \tag{3}$$

so that the resulting series could be interpreted as annualized percentage volatility at a daily frequency. Table **1** presents the descriptive statistics of annualized volatility for seven asset classes in pre- and post-war periods. The figures indicate a reallocation of volatility across asset classes between the two periods, with US10Y and WTI showing decreased volatility and gold and silver exhibiting increased volatility from the pre-war to post-war period. Average annualized volatility for gold and silver increased from 15.7% to 17.3% and from 29.4% to 33.3%, respectively, alongside lower standard deviations, suggesting a regime of moderately higher but more stable volatility. By contrast, both the mean and dispersion of volatility for the US 10-year yield and WTI crude oil declined (from 41.3% to 30.3% and from

Table 1. Descriptive statistics of annualized volatility (in percentage) for seven asset classes.

	Gold	Silver	S&P500	US10Y	WTI	DXY	BTC
Pre-war Period							
Mean	15.724	29.384	13.833	41.340	44.470	6.228	72.659
Median	13.175	23.673	10.592	31.450	33.040	5.795	59.633
Minimum	4.025	5.873	1.941	0.000	10.730	0.197	6.866
Maximum	94.049	296.965	96.658	728.990	1430.000	29.834	419.504
Standard deviation	9.686	21.625	11.307	46.531	57.965	2.991	49.742
Skewness	2.984	4.118	2.850	7.062	14.758	2.383	2.242
Kurtosis	17.013	35.212	14.726	78.559	325.614	14.489	11.343
Post-war Period							
Mean	17.336	33.307	13.777	30.262	39.290	7.870	52.080
Median	15.643	29.761	11.610	25.699	34.250	6.960	45.857
Minimum	4.496	4.489	1.892	3.862	11.100	0.211	4.946
Maximum	81.343	187.444	117.405	126.099	231.950	34.292	250.493
Standard deviation	8.537	16.419	9.198	17.252	21.123	3.823	28.751
Skewness	2.029	2.422	3.525	1.844	2.650	1.730	2.166
Kurtosis	10.249	14.902	29.244	7.559	16.093	8.389	11.156

Table 2. Correlations between gold and six asset classes in daily logarithmic returns - by year.

Year	Silver	S&P500	US10Y	WTI	DXY	BTC
2018	0.8150	-0.0067	-0.1500	0.0661	-0.5490	-0.0909
2019	0.8100	-0.2710	-0.5150	-0.0432	-0.4440	0.1850
2020	0.7800	0.1750	-0.0723	0.1140	-0.2610	0.3670
2021	0.7690	0.0565	-0.2620	0.0214	-0.4020	-0.0234
2022	0.8110	0.1090	-0.3210	0.3800	-0.4440	0.0835
2023	0.7610	-0.0098	-0.4780	0.0209	-0.4840	0.1240
2024	0.7720	0.1800	-0.2270	0.1850	-0.3020	0.1440
2025	0.6500	0.0266	-0.0776	0.0802	-0.4210	0.0594

44.5% to 39.3%), consistent with a partial normalization after the extreme swings observed during the COVID-19 shock and the immediate aftermath of the Russian invasion.

Tables **2** and **3** report the correlations between gold and six other variables in terms of daily logarithmic returns and annualized volatility. The relationship between gold and the S&P 500 is clearly time-varying and differs across the return and volatility dimensions. In returns, annual correlations are negative in 2018, 2019 and 2023, consistent with gold offering partial protection against equity downside in those years. However, correlations turn positive in 2020-2022 and 2024-2025, with particularly high values during the COVID-19 episode in 2020, the onset of the Russia-Ukraine war in 2022, and the beginning of the sharp gold price rally in 2024. These positive correlations imply that gold and the S&P 500 move in tandem rather than offsetting each other, in line with recent evidence that gold's safe-haven properties vis-à-vis equities have weakened in the post-2010 period, especially during major macro-financial shocks.

For volatility, correlations between gold volatility and S&P 500 volatility lie in a moderate to high positive range from 0.1490 to 0.6060 during 2018-2025, indicating that spikes in equity volatility tend to coincide with higher gold volatility. This pattern suggests that gold and equities increasingly share common volatility drivers even when their average return correlation is relatively modest.

4. METHODOLOGY

4.1. Diebold and Yilmaz Connectedness

For measuring the connectedness among different asset classes that arises due to heterogeneous frequency responses

Table 3. Correlations between gold and six asset classes in annualized volatilities - by year.

Year	Silver	S&P500	US10Y	WTI	DXY	BTC
2018	0.6660	0.1490	0.2180	0.0127	0.2810	0.1080
2019	0.7390	0.3220	0.6050	0.3320	0.3820	0.1190
2020	0.7590	0.6060	0.3890	0.2830	0.6070	0.5000
2021	0.7070	0.2040	0.1150	0.0946	0.3830	0.1460
2022	0.7000	0.3490	0.4200	0.4870	0.4680	0.3270
2023	0.6340	0.3270	0.4800	0.3550	0.4370	0.2090
2024	0.7190	0.3070	0.3960	0.0425	0.4280	0.2630
2025	0.5970	0.2790	0.2300	0.2740	0.2150	0.1530

to shocks, we follow the approach of Diebold and Yilmaz (2012, 2014) which is based on dynamic variance decomposition from vector-autoregression (VAR) model. Let $x_t = (x_{1t}, \dots, x_{Nt})'$ be an $N \times 1$ vector of stationary variables described by the VAR(p) framework as

$$x_t = \sum_{k=1}^{p} \Phi_k x_{t-k} + \varepsilon_t \qquad (4)$$

where Φ_k are $N \times N$ coefficient matrices and innovations $\varepsilon_t \sim (0, \Sigma)$ have covariance matrix Σ. The associated moving-average (MA) representation is $x_t = \sum_{h=0}^{\infty} A_h \varepsilon_{t-h}$, with $A_0 = I_N$ and A_h obtained recursively from $\{\Phi_k\}$. Following Diebold and Yilmaz, connectedness is measured via generalized forecast error variance decompositions (GFEVD), which quantify how much of the H-step-ahead forecast error variance of each variable is due to shocks in all variables. The generalized H-step-ahead variance decomposition element from variable j to variable i is

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' A_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} e_i' A_h \Sigma A_h' e_i} \qquad (5)$$

where σ_{jj} is the j-th diagonal element of Σ and e_i is the i-th selection vector. Because generalized variance shares do not necessarily sum to one across j, each row is normalized:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{k=1}^{N} \theta_{ik}^{g}(H)} \qquad (6)$$

so that $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$ and denote the normalized decomposition matrix by $\tilde{\Theta}^{g}(H) = [\tilde{\theta}_{ij}^{g}(H)]_{i,j=1}^{N}$. The Diebold–Yilmaz total connectedness index (TCI) at horizon H summarizes the share of system-wide forecast error variance arising from cross-variable shocks:

$$C^{\mathrm{TCI}}(H) = 100 \times \frac{\sum_{i=1}^{N} \sum_{j=1, j\neq i}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i=1}^{N} \sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} = 100 \times \frac{1}{N} \sum_{i=1}^{N} \sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ij}^{g}(H) \qquad (7)$$

The directional connectedness from others to variable i will be:

$$C_{i\leftarrow\cdot}(H) = 100 \times \frac{1}{N} \sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ij}^{g}(H) \qquad (8)$$

The directional connectedness from variable i to others will be:

$$C_{i\rightarrow\cdot}(H) = 100 \times \frac{1}{N} \sum_{\substack{j=1 \\ j\neq i}}^{N} \tilde{\theta}_{ji}^{g}(H) \qquad (9)$$

Net directional connectedness of variable i will be:

$$C_i^{\mathrm{NET}}(H) = C_{i\rightarrow\cdot}(H) - C_{i\leftarrow\cdot}(H) \qquad (10)$$

where positive values indicate net transmission and negative values net reception of shocks. Pairwise net connectedness capturing the dominant direction of spillovers between i and j will be:

$$C_{ij}^{\mathrm{NET}}(H) = 100 \times \frac{1}{N} \left(\tilde{\theta}_{ji}^{g}(H) - \tilde{\theta}_{ij}^{g}(H)\right) \qquad (11)$$

4.2. Spectral Representation and Frequency-domain Connectedness

Baruník and Křehlík (2018) extend the DY framework by decomposing connectedness across frequencies using the spectral representation of variance decompositions. By considering a frequency response function as the Fourier transform of the impulse responses:

$$\Psi(\omega) = \sum_{h=0}^{\infty} A_h e^{-i\omega h}, \omega \in [-\pi, \pi] \qquad (12)$$

and the spectral density of x_t at frequency ω is $S_x(\omega) = \Psi(\omega)\,\Sigma\,\Psi(\omega)'$. The generalized causation spectrum from variable j to variable i is

$$f_{ij}(\omega) = \frac{\sigma_{jj}^{-1} \left| e_i' \Psi(\omega) \Sigma e_j \right|^2}{e_i' S_x(\omega) e_i}, \omega \in [-\pi, \pi] \qquad (13)$$

which measures the share of the spectrum of variable i at frequency ω attributable to shocks in variable j. To weight frequencies by their contribution to the unconditional variance of x_{it}, define

$$\Gamma_i(\omega) = \frac{e_i' S_x(\omega) e_i}{\frac{1}{2\pi} \int_{-\pi}^{\pi} e_i' S_x(\lambda) e_i \, d\lambda} \qquad (14)$$

For a frequency band $d = (a,b) \subset [-\pi,\pi]$, the band-specific generalized variance decomposition from j to i is

$$\theta_{ij}(d) = \frac{1}{2\pi}\int_a^b f_{ij}(\omega)\,\Gamma_i(\omega)\,d\omega \tag{15}$$

Over a partition $\Delta = \{d_1,\dots,d_K\}$ of $[-\pi,\pi]$, these satisfy $\sum_{k=1}^{K}\theta_{ij}(d_k) = \theta_{ij}^{g}(\infty)$, so the long-horizon GFEVD is decomposed across frequency bands. Band-specific variance decompositions are again row-normalized:

$$\tilde{\theta}_{ij}(d) = \frac{\theta_{ij}(d)}{\sum_{k=1}^{N}\theta_{ik}(d)} \tag{16}$$

so that $\sum_{j=1}^{N}\tilde{\theta}_{ij}(d) = 1$ and the normalized matrix on band d is $\widetilde{\Theta}(d) = [\tilde{\theta}_{ij}(d)]_{i,j=1}^{N}$. Within connectedness on band d is defined analogously to the DY total connectedness, but computed using $\widetilde{\Theta}(d)$:

$$C_W(d) = 100 \times \left(1 - \frac{\mathrm{Tr}\{\widetilde{\Theta}(d)\}}{\sum_{i=1}^{N}\sum_{j=1}^{N}\tilde{\theta}_{ij}(d)}\right) = 100 \times \frac{1}{N}\sum_{i=1}^{N}\sum_{\substack{j=1\\ j\neq i}}^{N}\tilde{\theta}_{ij}(d) \tag{17}$$

To link the frequency-domain measures to the overall DY TCI, Baruník and Křehlík introduce the variance share of band d is $\omega(d) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\theta_{ij}(d)}{\sum_{i=1}^{N}\sum_{j=1}^{N}\theta_{ij}^{g}(\infty)}$, and $C_F(d) = \omega(d)\,C_W(d)$ is defined as the frequency connectedness on band d. Summing over the partition recovers the long-horizon total connectedness, $\sum_{d\in\Delta} C_F(d) = C^{\mathrm{TCI}}(\infty)$ provides an exact decomposition of overall connectedness into short-, medium-, and long-run components depending on the chosen bands.

Frequency-domain analogues of the DY directional measures are obtained by aggregating the off-diagonal elements of $\widetilde{\Theta}(d)$ by row or column. The directional connectedness from others to variable *i* on band d will be:

$$C_{i\leftarrow\cdot}(d) = 100 \times \frac{1}{N}\sum_{\substack{j=1\\ j\neq i}}^{N}\tilde{\theta}_{ij}(d) \tag{18}$$

From variable i *to* others on band d will be:

$$C_{i\rightarrow\cdot}(d) = 100 \times \frac{1}{N}\sum_{\substack{j=1\\ j\neq i}}^{N}\tilde{\theta}_{ji}(d) \tag{19}$$

Net frequency connectedness of variable i at band d will be:

$$C_i^{\mathrm{NET}}(d) = C_{i\rightarrow\cdot}(d) - C_{i\leftarrow\cdot}(d) \tag{20}$$

which indicate whether variable i is a net transmitter ($C_i^{\mathrm{NET}}(d) > 0$) or receiver ($< 0$) of shocks at the corresponding horizon. Pairwise net measures can be defined using $\tilde{\theta}_{ij}(d)$ and $\tilde{\theta}_{ji}(d)$ as similar to formula (11).

5. EMPIRICAL FINDINGS

Given the sample sizes of 1,031 and 956 observations for the pre- and post-war periods, a dynamic analysis is implemented by employing a rolling window of 200 days, vector autoregressions of order 4, and H-step ahead forecast horizon of 20 days for the connectedness analysis. In the frequency-domain connectedness analysis, the spectrum is partitioned into three economically meaningful bands corresponding to short-, medium-, and long-term spillovers. Following the Baruník and Křehlík (2018) framework, the frequency space (0,π] is divided using the vector partition of 0, π/5, π/2, π, which maps into approximate horizons of 1-4, 5-10, and more than 10 trading days. This specification allows the connectedness measures to distinguish between very short-lived shocks, medium-horizon spillovers that are relevant for tactical trading, and more persistent effects that shape the longer-run transmission of risk across markets.

Tables **4** and **5** report the total and directional return spillovers across gold, silver, S&P 500 index, the US 10-year Treasury yield, WTI crude oil, the USD Index and Bitcoin in the pre- and post-war subsamples, while Figs. (**1** to **4**) provide a graphical representation of these connectedness patterns. The matrices show that overall connectedness rises after the Russia-Ukraine invasion, and the network diagrams also highlight a denser web of bilateral spillovers in the post-war period. Decomposing total connectedness into short-, medium- and long-term components reveals a clear shift in the frequency structure of spillovers: in the pre-war period, the long-term band accounts for 78.2% of total connectedness versus 13.3% and 8.5% for the short- and medium-term, whereas in the post-war period these weights move to 62.5%, 22.1% and 15.4%, respectively. This change implies that, while low-frequency spillovers driven by slow-moving macroeconomic cycles, monetary policy trends and structural repricing still dominate, shocks have become more short-lived and reactive in the post-war regime, with a larger share of cross-market transmission now taking place at higher frequencies as investors respond more aggressively to news and rebalance positions over horizons of a few days to a few weeks. The post-war environment is therefore characterized by faster information diffusion, more tactical trading behaviour and more frequent, but less persistent, propagation of shocks across the gold-equity-bond-oil complex.

The directional results document a substantial reconfiguration of roles across individual markets. Gold stands out as a strong net receiver in the pre-war period with a net connectedness of -10.94. This figure accords with gold's traditional safe-haven and diversifier role, whereby investors adjust gold positions in response to volatility in equities, oil and interest rates, so that variation in gold returns largely reflects incoming spillovers. The net receiver status of gold is driven predominantly by the long-term component of -13.99, indicating that it mainly absorbed longer-horizon shocks rather than by short- and medium-term originating in other asset classes. In the post-war period, gold's net connectedness moves much closer to zero (-1.26), with the key adjustment mainly in long-term from -13.99 to -2.67, while short- and medium-term net positions change only modestly. This suggests that the Russia-Ukraine conflict and the associated inflation shock altered the way gold interacts with the rest of the system: despite retaining some safe-haven and inflation-hedging properties, the pronounced 2024-2025 price boom and stronger co-movement with risk assets made gold more tightly integrated into the broader risk-taking cycle, so that shocks in gold increasingly both originate from and feed back into other markets rather than being predominantly one-way inflows. Silver exhibits an even more pronounced shift, moving from a net receiver of -8.08 pre-war to a net transmitter of 5.78 post-war, with the main swing again concentrated in the long-term band from -7.44 to 10.56, which points to silver evolving from a follower into an active source of longer-horizon spillovers as its price dynamics became more closely entwined with those of equities and other risk assets in the post-war period.

The US equity market transitions from being a net receiver before the war to a strong net transmitter afterwards. In the pre-war subsample, US stocks have a negative net connectedness of -7.57, indicating that they primarily absorb shocks emanating from bond yields and USD Index, consistent with a regime in which monetary policy surprises and the equity market behaves largely as a risk-taking endpoint. In the post-war subsample, however, US stocks become a major net transmitter with a net connectedness of 11.55, reflecting a situation in which equity-market moves increasingly drive rather than merely reflect cross-market spillovers. This reversal is consistent with the idea that, after the invasion and amid aggressive Fed tightening, global investors treated the US equity market as the central barometer of growth expectations and risk sentiment, so that war-related news, policy shifts and revisions in macro outlooks were rapidly capitalized into stock prices and then transmitted outward to other asset classes. As a result, equities emerge as a primary originator of shocks in the post-war period, raising their outgoing spillovers to the rest of the system.

A particularly noteworthy result concerns the US 10-year Treasury yield, which switches from being a super net transmitter before the war to a relatively weaker transmitter thereafter. In the pre-war sample, the 10-year yield has a net connectedness of 66.67, driven almost entirely by its long-term component of 67.15, implying that changes in the yield curve were a dominant source of low-frequency spillovers to other markets. This finding is consistent with the macro environment of 2018-2021, during which markets moved from late-cycle Fed tightening through a sharp growth scare and aggressive rate cuts, into the COVID-19 shock and a zero-rate QE regime; in such conditions, shifts in the 10-year yield closely tracked evolving expectations about growth, monetary policy and discount rates, and were therefore transmitted strongly to equities, gold, oil and the USD. In the post-war period, the US 10-year yield remains a net transmitter but with a substantially lower net connectedness of 17.66, indicating that its marginal influence on other assets has weakened. The 2022-2023 inflation shock, the fastest Fed hiking cycle in decades and the breakdown of the traditional negative stock-bond correlation meant that higher yields were increasingly interpreted as a complex mixture of inflation risk, term-premium repricing, fiscal concerns and uncertainty about the duration of restrictive policy, which made the mapping from yield moves to equity and commodity returns more unstable. As inflation later peaked and equity performance became more driven by earnings, sectoral re-rating and AI-related themes, while long-term yields were shaped more by supply-demand and term-premium dynamics, the centrality of the 10-year yield as a transmitter of system-wide shocks diminished relative to the pre-war period.

Other assets exhibit more stable directional roles across pre- and post-war periods. WTI crude oil remains a strong net receiver throughout, with net connectedness of -20.04 pre-war and -21.03 post-war, indicating that oil prices are primarily driven by shocks originating in other markets rather than acting as a major source of spillovers into the broader system. This accords with evidence that, when oil is embedded in a multi-asset framework including equities, bonds and currencies, its return dynamics are more often explained by incoming macro-financial shocks than by outward transmission of volatility from the oil market. The USD Index also remains a net receiver, though its net position weakens from -11.87 to -4.18: in the pre-war period, Fed policy changes and trade tensions led investors to "buy dollars" in response to stress that was typically initiated in other markets, so dollar moves largely mirrored incoming spillovers, whereas after the war the combination of safe-haven flows and aggressive tightening meant that large moves in the USD began to feed back more visibly into global risk and commodity prices, reducing the extent to which it functioned as a pure sink. Bitcoin remains a net receiver in both subsamples, with net values of -8.17 and -8.51, suggesting that in a system dominated by large traditional assets it behaves as a peripheral speculative asset that mainly reacts to shocks rather than driving them, with its volatility and correlations responding to shifts in equity, bond and commodity markets rather than exerting persistent influence over those markets in either regime.

In summary, the empirical result demonstrates a pronounced intensification and reconfiguration of cross-market linkages following the outbreak of the Russia-Ukraine war. The aggregate level of return connectedness increases in the post-war period, with frequency decomposition indicating that this rise extends across multiple investment horizons. Although the long-term component remains predominant, its relative importance diminishes as short- and medium-term spillovers become more significant. The evidence suggests that the Russia-Ukraine conflict has not only amplified overall cross-market interconnectedness but has also reshaped the ranking of shock transmitters and recipients, with equities and, to a growing extent, precious metals assuming more central roles within the network. The increased prominence of shorter-horizon spillovers indicates that risk transmission across asset classes has become more rapid and unpredictable, thereby complicating conventional approaches to diversification, hedging, and the use of safe havens. Recognizing and understanding these regime shifts is essential for constructing resilient portfolios, developing effective stress-testing methodologies, and formulating policy measures amid ongoing geopolitical uncertainty.

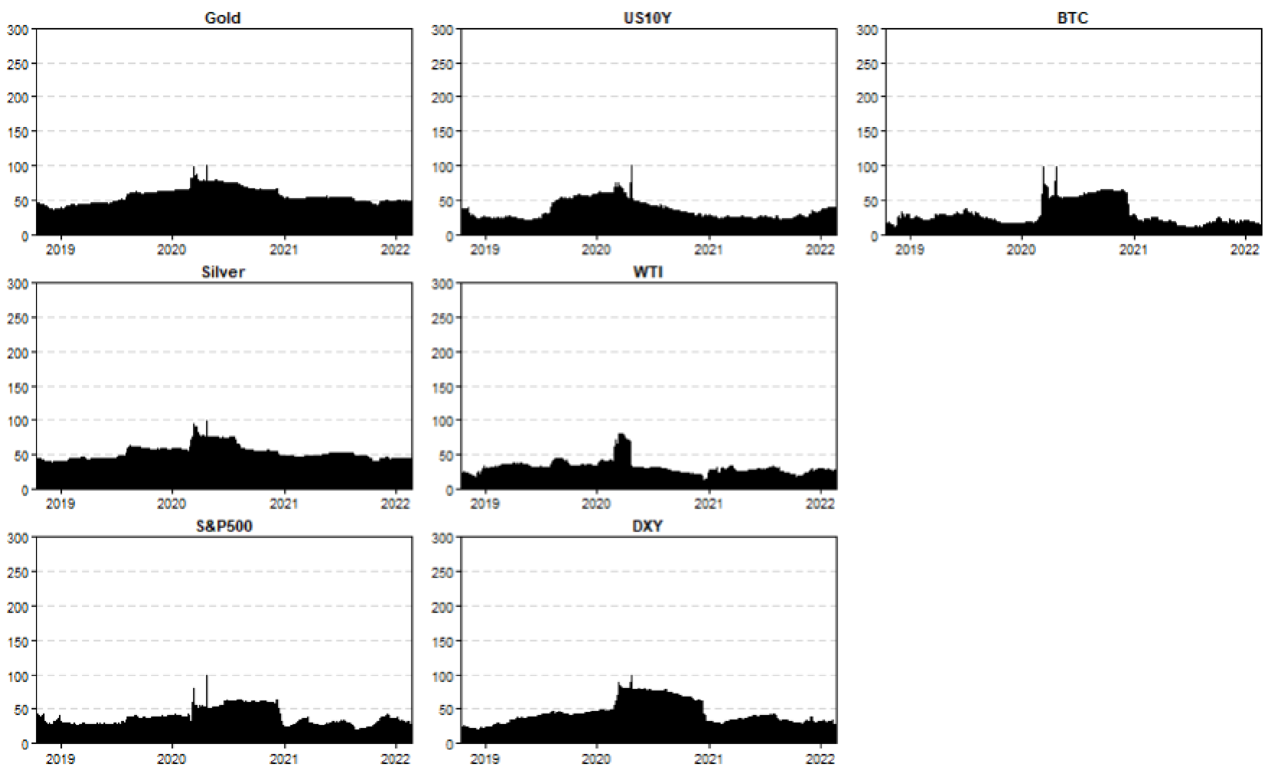
Table 4. Frequency Connectedness and spillover in annualized volatilities - Pre-war Period.

(i) Total								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	43.56	26.31	4.79	16.74	1.58	6.10	0.93	56.44

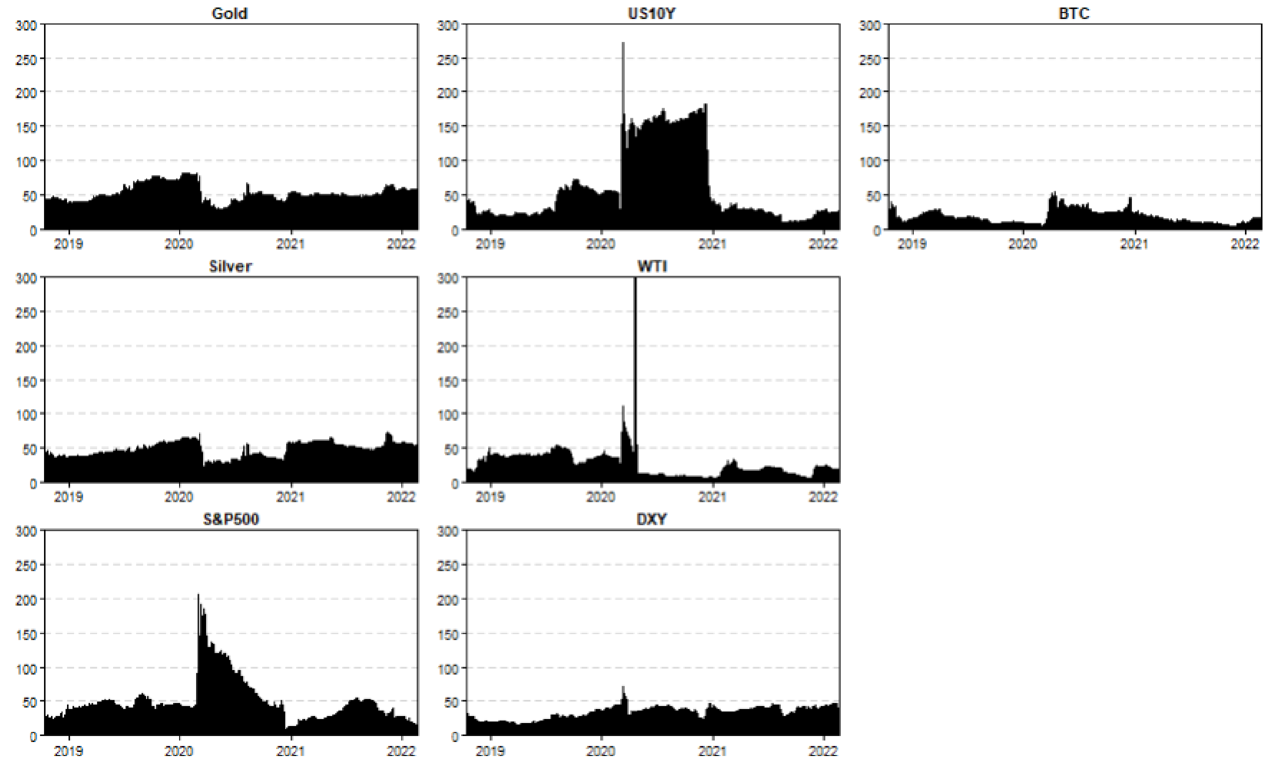
Silver	25.61	53.46	2.58	11.44	1.12	4.12	1.67	46.54
S&P500	3.34	1.65	60.39	24.74	1.13	7.81	0.95	39.61
US10Y	5.15	2.77	7.20	79.74	1.20	3.21	0.73	20.26
WTI	3.40	2.28	4.86	11.74	74.10	3.30	0.32	25.90
DXY	6.67	4.21	11.10	14.11	0.61	62.26	1.03	37.74
Bitcoin	1.33	1.25	1.50	8.16	0.22	1.33	86.20	13.80
TO	45.51	38.47	32.04	86.94	5.86	25.86	5.63	240.30
NET	-10.94	-8.08	-7.57	66.67	-20.04	-11.87	-8.17	
(ii) Short Term (1-4 days)								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	15.83	7.61	0.33	0.26	0.23	1.20	0.18	9.81
Silver	8.48	15.38	0.21	0.72	0.32	0.45	0.24	10.43
S&P500	0.23	0.14	8.18	0.34	0.06	0.11	0.15	1.05
US10Y	0.50	0.55	0.65	21.28	0.19	0.64	0.18	2.71
WTI	0.49	0.64	0.10	0.33	18.90	0.34	0.18	2.08
DXY	1.83	0.85	0.47	0.36	0.12	23.69	0.17	3.81
Bitcoin	0.55	0.62	0.23	0.39	0.14	0.06	27.82	2.00
TO	12.09	10.42	2.01	2.41	1.05	2.81	1.11	31.89
NET	2.28	-0.01	0.96	-0.30	-1.03	-1.00	-0.90	
(iii) Medium Term (5-10 days)								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	9.30	4.69	0.07	0.15	0.11	0.37	0.28	5.67
Silver	5.01	9.29	0.06	0.31	0.22	0.42	0.67	6.69
S&P500	0.31	0.39	7.17	0.26	0.11	0.29	0.30	1.66
US10Y	0.13	0.23	0.18	10.59	0.54	0.94	0.09	2.10
WTI	0.09	0.13	0.06	0.22	20.94	0.15	0.06	0.71
DXY	0.51	0.20	0.12	0.05	0.04	12.49	0.13	1.05
Bitcoin	0.39	0.42	0.51	0.93	0.00	0.27	18.77	2.52
TO	6.44	6.06	1.00	1.92	1.02	2.44	1.52	20.40
NET	0.77	-0.63	-0.66	-0.18	0.31	1.39	-1.00	
(iv) Long Term (more than 10 days)								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	18.43	14.00	4.38	16.33	1.25	4.53	0.47	40.96
Silver	12.11	28.79	2.31	10.41	0.58	3.25	0.77	29.43
S&P500	2.80	1.11	45.05	24.14	0.95	7.40	0.49	36.90
US10Y	4.52	1.99	6.37	47.87	0.47	1.63	0.46	15.45
WTI	2.82	1.51	4.71	11.19	34.26	2.81	0.08	23.11
DXY	4.33	3.16	10.51	13.70	0.45	26.08	0.73	32.88
Bitcoin	0.39	0.21	0.76	6.83	0.08	1.00	39.62	9.27

TO	26.98	21.99	29.03	82.60	3.79	20.62	3.00	188.00
NET	-13.99	-7.44	-7.87	67.15	-19.32	-12.26	-6.27	

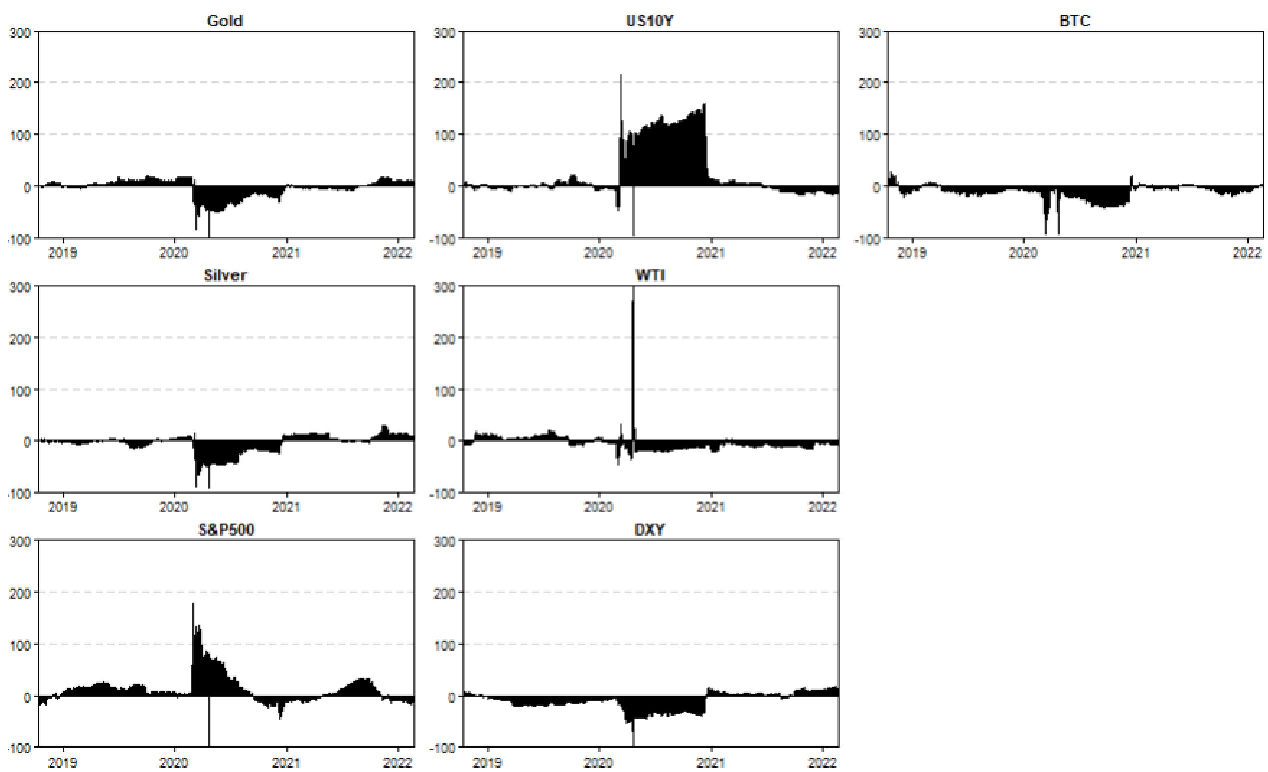
(i) Total spillover



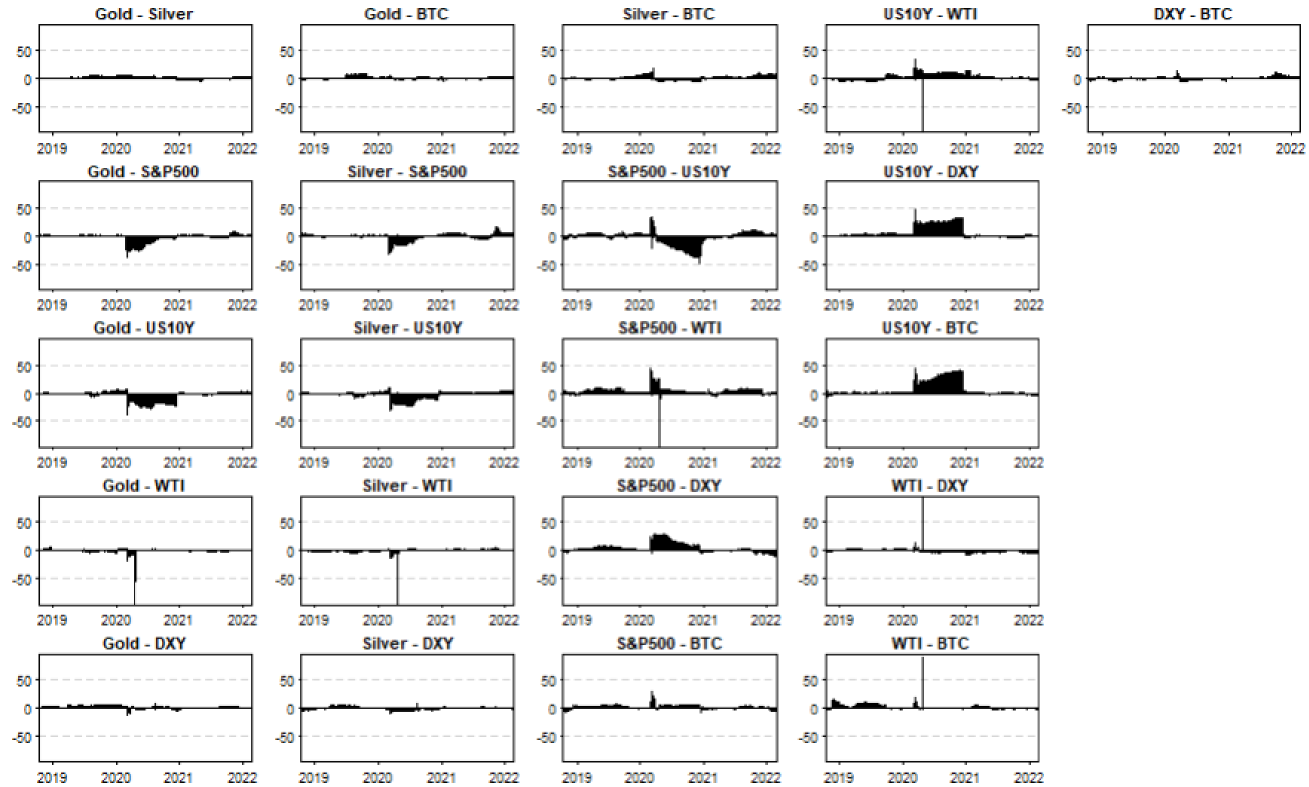
(ii) Directional spillover - FROM



(iii) Directional spillover – TO

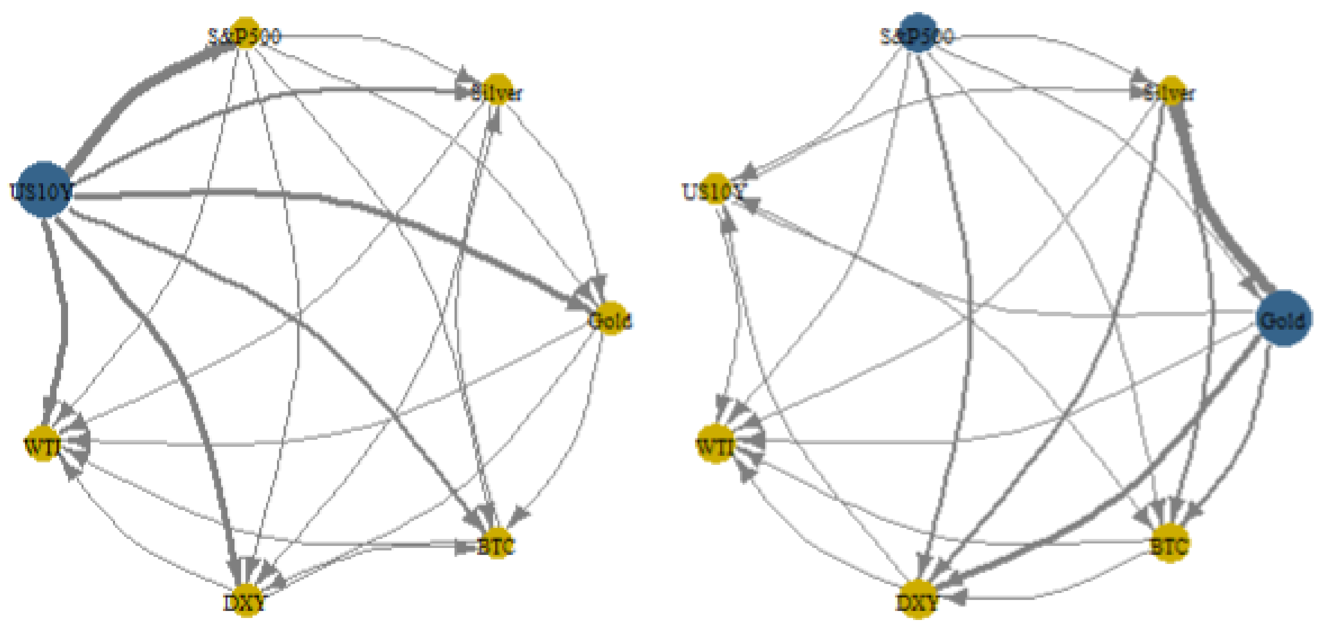


(iv) Directional spillover - NET



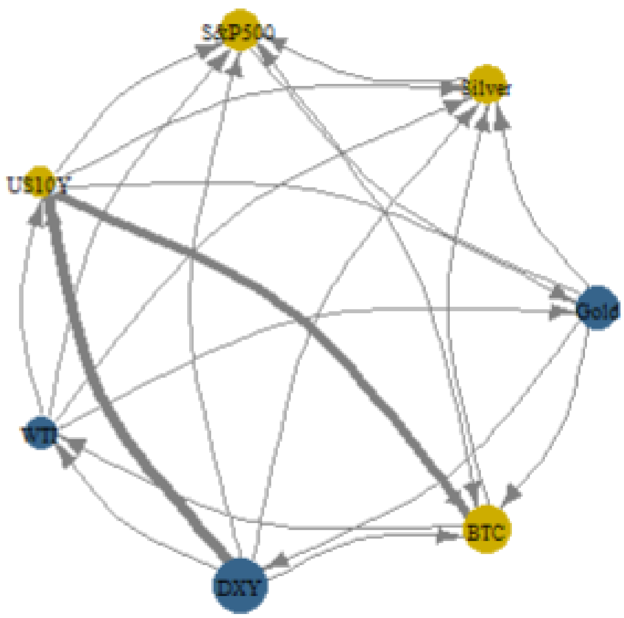
(v) Directional spillover - NET Pairwise

Fig. (1). Spillover diagram in annualized volatilities - Pre-war Period.

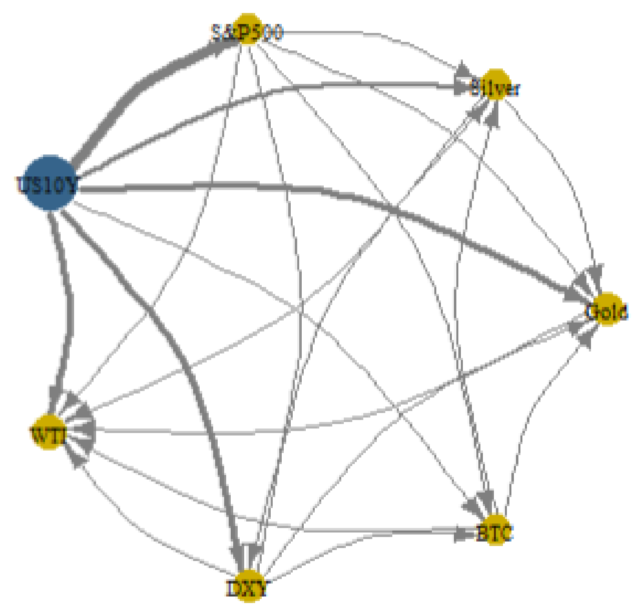


(i) Total

(ii) Short-Term (1-4 days)



(iii) Medium-Term (5-10 days)



(iv) Long-Term (more than 10 days)

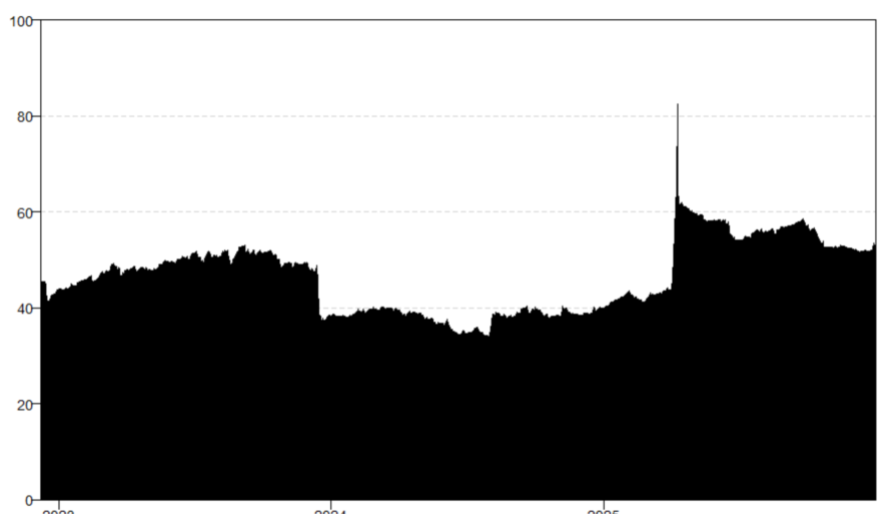
Fig. (2). NET Pairwise connectedness network in annualized volatilities – Pre-war Period.

Note: This figure follows the methodology of Diebold and Yilmaz (2012, 2014) to present network graphs depicting the net pairwise directional connectedness among seven variables. Arrowheads indicate the direction of positive net direct connectedness from the source variable to others, while arrow thickness represents the strength of the net pairwise directional connectedness. Yellow node represents it is a net receiver, blue node represents a net transmitter, and the radius of each circle reflects the magnitude of its net connectedness.

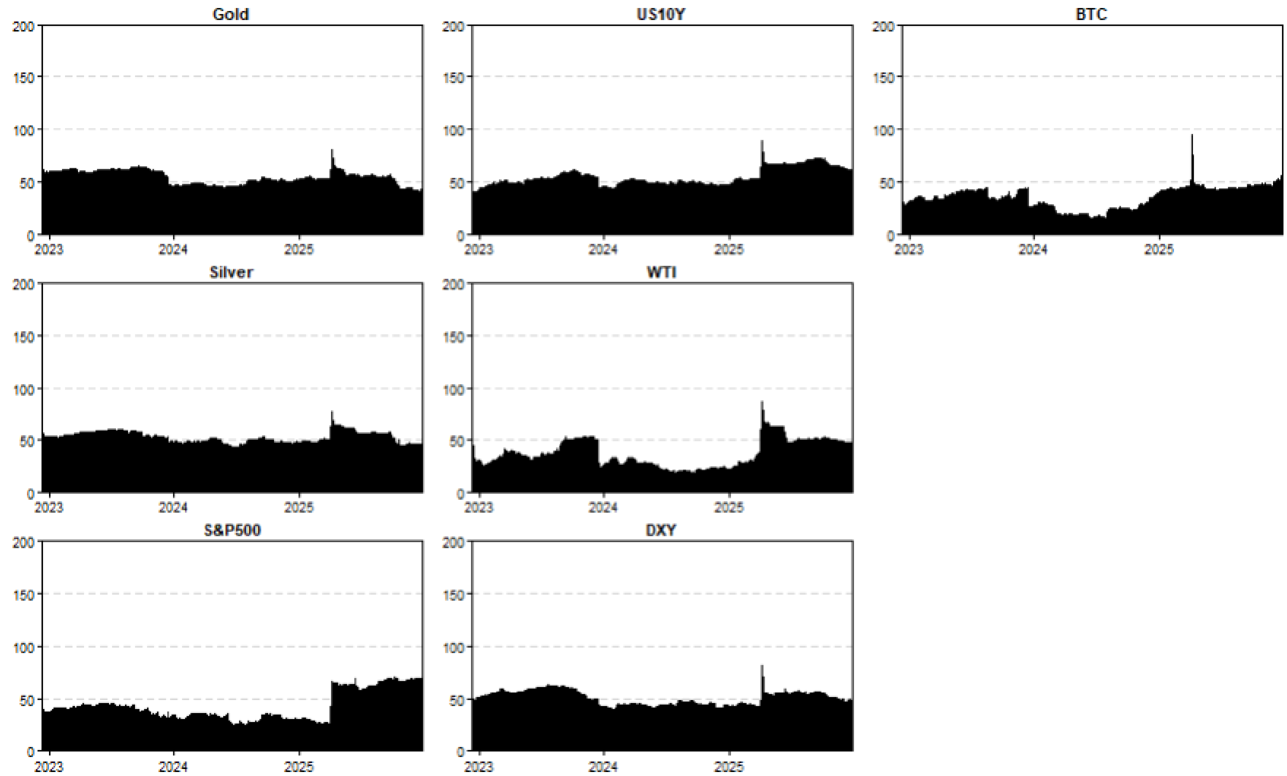
Table 5. Frequency Connectedness and spillover in annualized volatilities - Post-war Period.

(i) Total								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	54.28	24.50	5.19	4.36	3.71	6.30	1.66	45.72
Silver	23.97	57.78	4.08	4.76	2.73	4.87	1.81	42.22
S&P500	3.85	7.76	60.33	12.00	4.61	7.67	3.77	39.67
US10Y	3.00	3.74	12.07	57.71	6.24	11.66	5.59	42.29
WTI	4.03	4.06	8.30	18.37	56.40	6.69	2.15	43.60
DXY	6.41	4.59	11.90	14.22	4.34	56.13	2.40	43.87
Bitcoin	3.19	3.35	9.67	6.23	0.95	2.49	74.11	25.89
TO	44.45	48.00	51.21	59.95	22.57	39.69	17.38	283.26
NET	-1.26	5.78	11.55	17.66	-21.03	-4.18	-8.51	
(ii) Short Term (1-4 days)								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	19.64	8.59	0.52	1.43	1.01	2.78	0.73	15.06
Silver	9.60	21.36	0.95	1.66	0.75	1.76	0.59	15.31
S&P500	0.68	0.64	12.86	1.18	0.52	0.88	1.00	4.90
US10Y	1.30	1.13	1.10	14.33	0.42	2.71	0.60	7.26
WTI	0.88	0.48	0.47	0.27	19.34	0.59	0.10	2.79

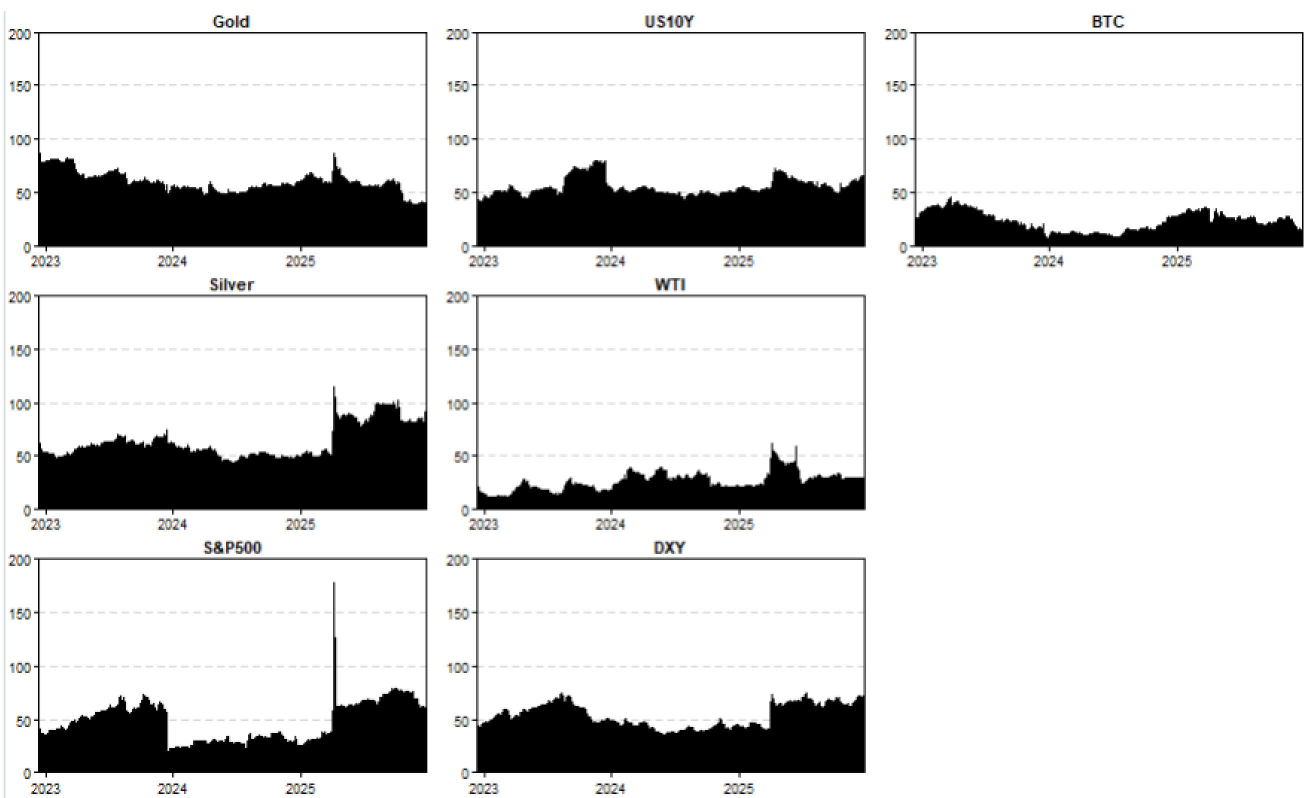
DXY	3.07	2.07	0.76	3.86	0.77	21.89	0.43	10.96
Bitcoin	0.73	0.71	1.94	1.47	0.26	1.17	26.31	6.27
TO	16.26	13.61	5.74	9.87	3.72	9.90	3.45	62.56
NET	1.20	-1.69	0.84	2.61	0.93	-1.07	-2.82	
(iii) Medium Term (5-10 days)								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	11.08	4.63	1.17	1.15	0.89	1.67	0.53	10.05
Silver	5.79	12.85	1.10	1.41	0.94	1.60	0.65	11.49
S&P500	0.28	0.48	9.76	0.88	0.40	0.38	0.68	3.10
US10Y	0.86	0.88	0.77	6.46	0.37	1.32	0.53	4.73
WTI	0.85	0.70	0.82	0.75	9.30	0.34	0.13	3.59
DXY	1.65	1.11	0.86	1.90	0.49	11.38	0.85	6.85
Bitcoin	0.83	0.60	1.10	0.92	0.20	0.27	18.25	3.92
TO	10.25	8.40	5.82	7.01	3.29	5.58	3.37	43.73
NET	0.20	-3.09	2.73	2.28	-0.30	-1.28	-0.55	
(iv) Long Term (more than 10 days)								
	Gold	**Silver**	**S&P500**	**US10Y**	**WTI**	**DXY**	**Bitcoin**	**FROM**
Gold	23.56	11.28	3.49	1.77	1.81	1.85	0.40	20.60
Silver	8.58	23.57	2.03	1.70	1.04	1.51	0.57	15.42
S&P500	2.89	6.64	37.71	9.94	3.70	6.41	2.10	31.67
US10Y	0.83	1.72	10.21	36.92	5.45	7.63	4.47	30.30
WTI	2.31	2.89	7.01	17.35	27.75	5.76	1.91	37.23
DXY	1.69	1.41	10.28	8.47	3.08	22.86	1.12	26.05
Bitcoin	1.64	2.04	6.63	3.84	0.49	1.06	29.56	15.70
TO	17.94	25.98	39.65	43.07	15.56	24.22	10.57	176.98
NET	-2.67	10.56	7.98	12.77	-21.67	-1.83	-5.13	



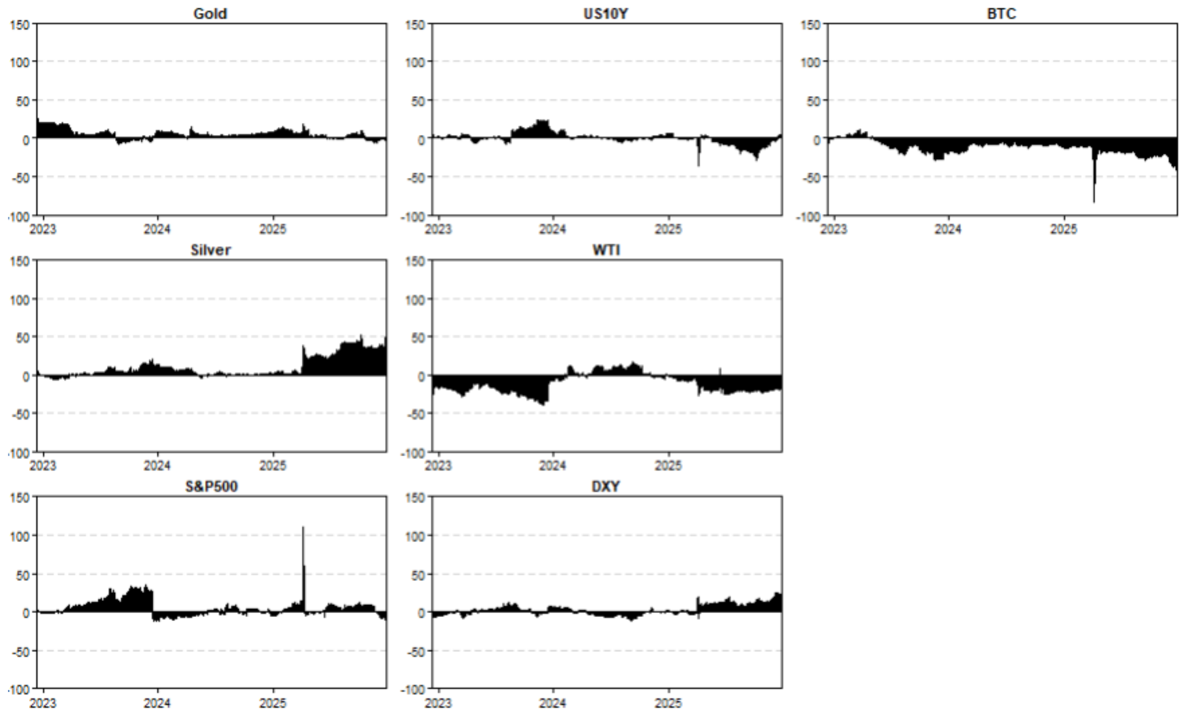
(i) Total spillover



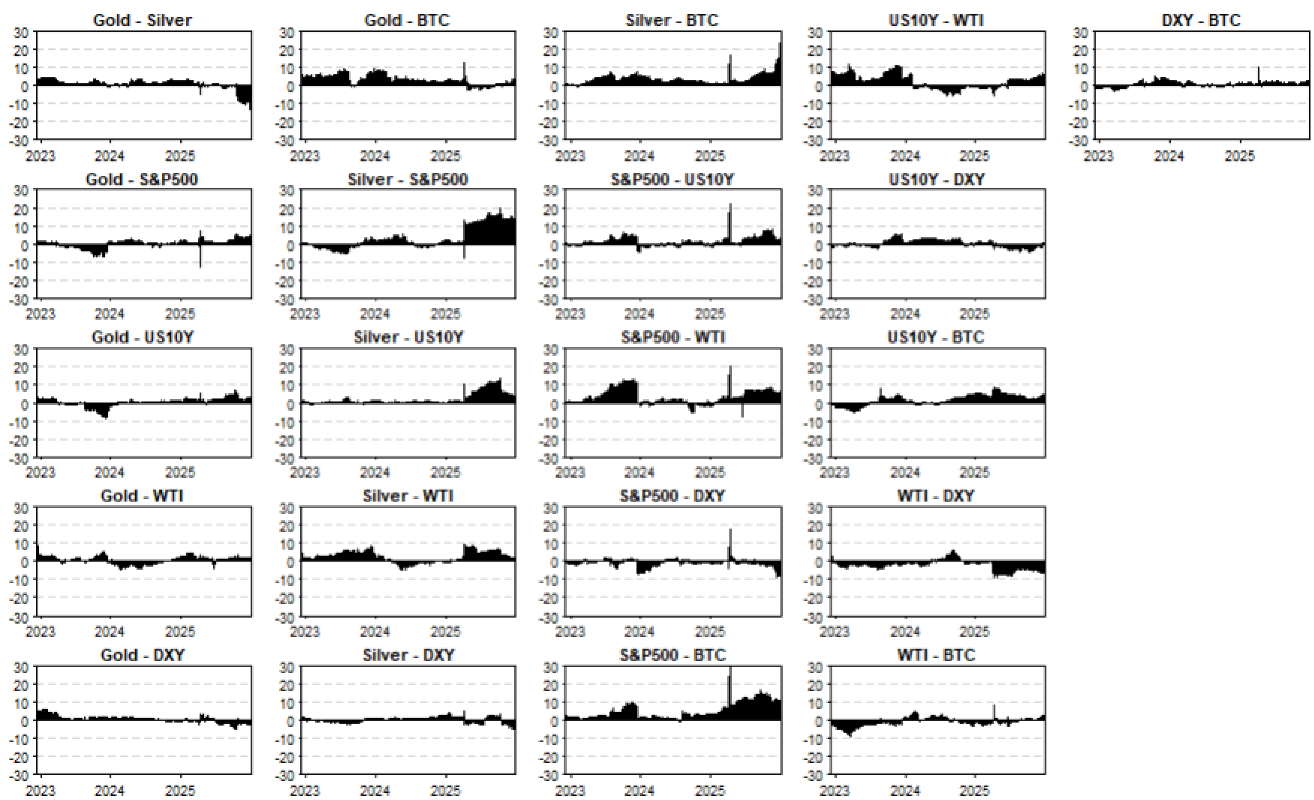
(ii) Directional spillover – FROM



(iii) Directional spillover – TO

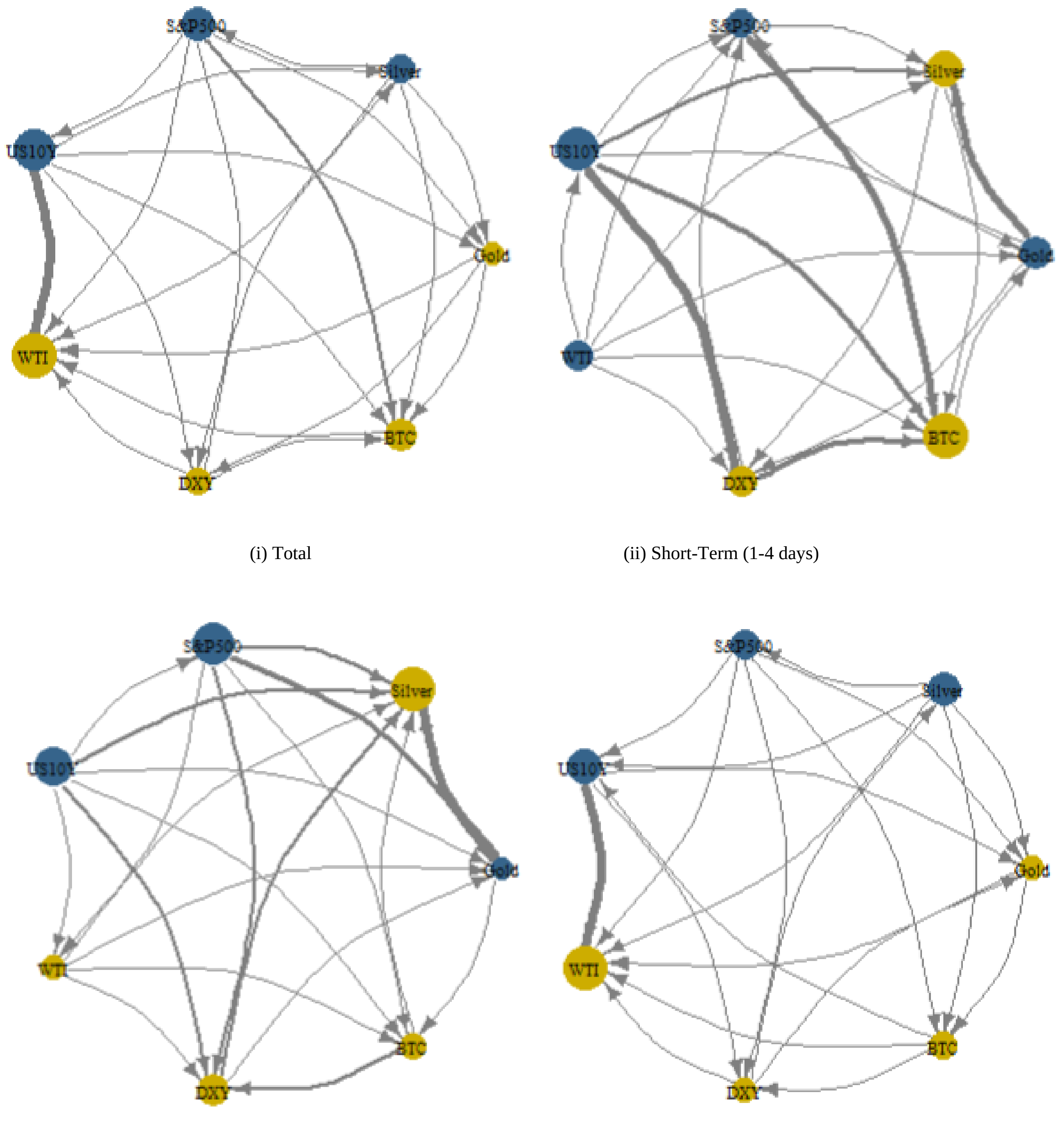


(iv) Directional spillover – NET



(v) Directional spillover - NET Pairwise

Fig. (3). Spillover diagram in annualized volatilities - Post-war Period.



(i) Total

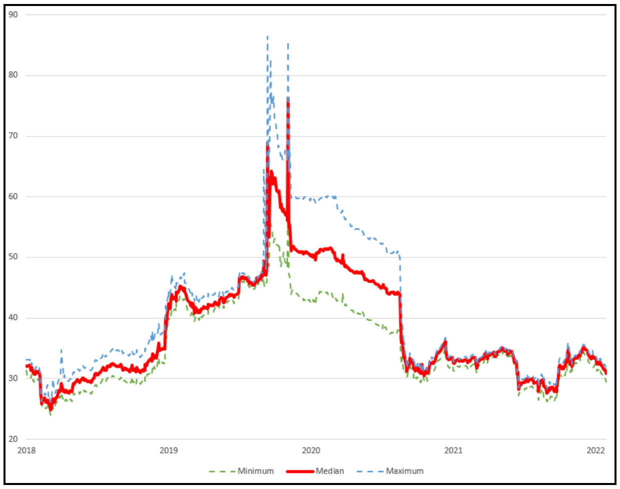
(ii) Short-Term (1-4 days)

(iii) Medium-Term (5-10 days)

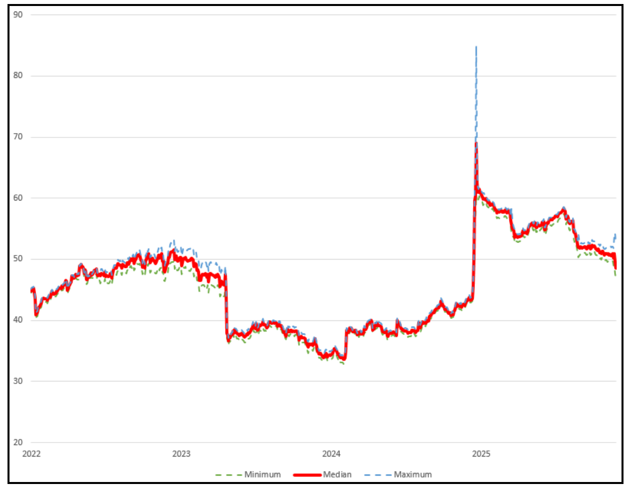
(iv) Long-Term (more than 10 days)

Fig. (4). NET Pairwise connectedness network in annualized volatilities – Post-war Period.

Note: This figure follows the methodology of Diebold and Yilmaz (2012, 2014) to present network graphs depicting the net pairwise directional connectedness among seven variables. Arrowheads indicate the direction of positive net direct connectedness from the source variable to others, while arrow thickness represents the strength of the net pairwise directional connectedness. Yellow node represents it is a net receiver, blue node represents a net transmitter, and the radius of each circle reflects the magnitude of its net connectedness.



(i) Pre-war Period



(ii) Post-war Period

Fig. (5). Sensitivity of the spillover to the forecast horizon (maximum, minimum, and median values for 5-, 6-, 7-, 8-, 10-, 20-, and 30-day forecast horizons).

For robustness test, we reassess volatility connectedness by considering a range of various forecast horizons (5, 6, 7, 8, 10, 20, and 30 days) and plot the minimum, maximum, and median values of the total volatility spillovers. As shown in Fig. (**5**), the spillover patterns remain consistent across different horizons and confirm the reliability of our results.

CONCLUSION

This study has examined how the Russia-Ukraine war reshaped the volatility connectedness among gold, silver, equities, bonds, oil, the US dollar and Bitcoin by combining the Diebold-Yilmaz time-domain framework with its Baruník-Křehlík frequency-domain extension over an eight-year sample from 2018 to 2025. The analysis, based on daily volatility measures and a pre-war/post-war split, shows that the conflict coincided with both an intensification of overall cross-market spillovers and a marked reconfiguration of the roles played by traditional and alternative assets in the global risk transmission network.

The main empirical findings can be summarized along three dimensions. First, total volatility connectedness rises in the post-war period, indicating a more tightly integrated multi-asset environment in which shocks propagate more quickly and broadly across markets. Frequency decomposition reveals that while long-term spillovers continue to dominate, their relative weight declines in favour of short- and medium-term components, implying that risk transmission has become more reactive and less anchored in slow-moving macroeconomic forces. Second, the directional results document a pronounced role reversal among key markets: US equities and, to a lesser extent, precious metals move toward the centre of the spillover network as net transmitters or near-neutral nodes, whereas the influence of the US 10-year Treasury yield as a "super" long-horizon transmitter weakens substantially after the outbreak of war. Third, gold evolves from a clear net receiver of predominantly long-term shocks before the war to a much more interconnected asset with near-zero net connectedness, while silver shifts from net receiver to net transmitter, signalling that both metals have become more deeply embedded in the broader risk-taking cycle rather than functioning purely as passive diversifiers.

These results carry several implications for portfolio construction and risk management under prolonged geopolitical stress. The increased level of aggregate connectedness and the rising importance of higher-frequency spillovers suggest that conventional diversification strategies that rely on stable cross-asset correlations and the slow diffusion of shocks may be less effective in the current regime. The attenuation of gold's long-horizon net receiver status, together with its stronger comovement with equities and other risk assets, cautions against treating gold as a uniformly reliable safe haven or hedge and instead supports viewing it as a state-dependent risk mitigant whose protective properties vary with macro-financial conditions and market regimes. At the same time, the persistent net receiver status of WTI, the US dollar and Bitcoin within the system underscores that these markets remain more reactive than generative in the volatility network, reinforcing their interpretation as recipients of macro-financial shocks rather than dominant transmitters of instability.

More broadly, the evidence points to a structural shift in how war-related uncertainty and financial instability jointly shape the global transmission of risk across asset classes. The Russia-Ukraine conflict appears not only to have strengthened cross-market linkages but also to have compressed the time scale over which shocks are priced, with a larger share of volatility spillovers now materializing over horizons relevant to tactical trading and short-term risk management. For investors, this underscores the need to incorporate time- and frequency-varying connectedness metrics, rather than static correlation estimates, into portfolio design, stress testing and hedging programmes. For policymakers and regulators, the heightened and faster-moving interconnectedness documented in this study highlights the importance of monitoring multi-asset volatility networks when assessing systemic risk, particularly during episodes of sustained geopolitical tension.

The analysis also suggests several avenues for future research. First, extending the sample to incorporate subsequent geopolitical developments and monetary policy regimes would help to assess the persistence and potential reversals of the post-war connectedness patterns identified here. Second, combining high-frequency intraday data with alternative measures of geopolitical risk and financial stress could provide a more granular view of how specific news events propagate through the volatility network across horizons. Third, enriching the asset set to include additional commodities, regional equity and bond indices, and other digital assets would allow researchers to test whether the regime shifts in gold's connectedness documented in this paper generalize to a broader set of safe haven candidates and speculative vehicles. Addressing these questions would further enhance understanding of gold's evolving role in modern portfolios and contribute to the wider literature on asset-market behaviour under extreme and persistent geopolitical uncertainty.

DATA AVAILABILITY

Data will be made available on request.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Eddie Y. M. Lam: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review and editing.

DECLARATION OF COMPETING INTEREST

The author declare that he has no conflicts of interest regarding this paper.

CONFIRMATION BY THE AUTHOR

The author confirms the following in relation to the submission of this paper:

- The work is original, not published elsewhere and not under review by another journal.
- The author meet authorship criteria and have approved the version to be published.
- All relevant contributions have been acknowledged.
- Any conflicts of interest are declared.
- No ethical approval is required for this paper.
- The author will be available to respond to queries after publication and take responsibility for corrections if necessary.
- Highlights
- The study examines volatility connectedness among gold, silver, and multiple asset classes over the full Russia-Ukraine conflict period and explicitly incorporating the explosive rally in gold and silver prices in 2024-2025.
- Overall volatility connectedness increases markedly in the post-war period.
- The frequency structure of spillovers shifts toward short-term horizons, indicating faster and more reactive risk transmission across markets.
- Gold evolves from a long-horizon net receiver of volatility shocks to a near-neutral, more integrated node in the multi-asset network, while silver becomes a net transmitter.

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