

Dynamic energy hedging and safe havens in BRICS Plus stock markets

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Abstract: This paper examines whether crude oil and natural gas act as diversifiers, hedges, and safe havens for BRICS Plus stock markets during the COVID-19 pandemic, the Russia–Ukraine conflict, and the Silicon Valley Bank collapse. Results indicate that crude oil serves as an effective diversifier in normal periods and provides strong safe-haven protection during extreme crises, especially for Russia, India, and China. Natural gas primarily serves as a stable diversifier and hedge, with stronger effects during downturns than during acute crises. Overall, crude oil demonstrates greater hedging effectiveness, offering important implications for dynamic risk management and portfolio allocation under uncertainty.

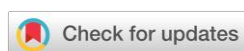
Keywords: BRICS Plus stock markets; crude oil; natural gas; diversification; hedging effectiveness; safe haven; financial crises; portfolio management; risk management

JEL Classification: G11, G15, Q41, C58

1. Introduction

In recent years, a series of extraordinary black swan events has profoundly reshaped global financial markets, exposing structural vulnerabilities in both developed and emerging economies. The COVID-19 pandemic, first reported in Wuhan, China, on December 31, 2019, triggered an unprecedented global economic and financial shock. Widespread lockdowns, disruptions in supply chains, and severe contractions in economic activity led to sharp declines in industrial production and global trade, ultimately eroding investor confidence and increasing stock market volatility (Jeribi et al., 2020; Jeribi & Manzli, 2020; Fakhfekh et al., 2023; Snene Manzli & Jeribi, 2024a, 2024b). The pandemic affected countries unevenly due to differences in healthcare capacity, economic resilience, and policy responses, with emerging markets being particularly vulnerable because of limited fiscal capacity and strong dependence on international trade (Chaudhary et al., 2020; Caporale et al., 2022; Mishra & Mishra, 2022; Kumar, 2024).

Soon after, the Russia–Ukraine conflict, which began on February 24, 2022, introduced a new dimension of geopolitical uncertainty into global financial markets. The conflict disrupted energy supply chains, intensified inflationary pressures, and generated significant volatility across international markets (Boungou & Yatié, 2022; Liadze et al., 2022; Karamati & Jeribi, 2023). Global stock markets experienced sharp negative returns, particularly in sectors highly exposed to energy prices and international trade (Ahmed et al., 2022; Boubaker et al., 2022). More recently, the collapse of Silicon Valley Bank (SVB) on March 10, 2023, highlighted the fragility of financial institutions within an interconnected global banking system. Although the financial contagion was relatively short-lived, the event demonstrated how institution-specific failures can rapidly transmit shocks across



Citation: Belguith, R., & Manzli, Y.S. (2026). Dynamic energy hedging and safe havens in BRICS Plus stock markets. *Modern Finance*, 4(2), 37–58.

Accepting Editor: Adam Zaremba

Received: 23 September 2025

Accepted: 1 April 2026

Published: 18 April 2026

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global markets through capital flows, investor sentiment, and interbank linkages (Akhtaruzzaman et al., 2023; Dammak et al., 2024; Vu et al., 2023).

These crises differ significantly in their underlying transmission mechanisms. While the COVID-19 pandemic primarily represents a demand-side shock, the Russia–Ukraine conflict reflects supply-driven and geopolitical disturbances, and the SVB collapse illustrates financial-institutional contagion. Such heterogeneity challenges the assumption that financial assets behave uniformly across crises and highlights the importance of reassessing the hedging and safe-haven properties of alternative assets under different systemic shocks.

In this context, energy commodities such as crude oil and natural gas have become increasingly relevant in global financial markets. Unlike traditional safe-haven assets such as gold or currencies, energy commodities are deeply integrated into global production networks, trade flows, and macroeconomic dynamics. Their prices are highly sensitive to geopolitical tensions, supply disruptions, sanctions, and global economic conditions (Mensi et al., 2021; Ghazani et al., 2023). Consequently, fluctuations in oil and gas markets can both reflect and transmit financial and economic shocks across countries. For instance, the sharp increase in energy prices during the Russia–Ukraine conflict significantly affected inflation dynamics and monetary policy decisions in many economies, particularly those heavily dependent on energy imports (Liadze et al., 2022; Majumder, 2022).

Against this background, the present study focuses on the BRICS Plus economies, a heterogeneous group of emerging and frontier markets including Brazil, Russia, India, China, South Africa, Egypt, Argentina, Saudi Arabia, and the United Arab Emirates. Unlike the traditional BRICS group, which is often analyzed as a relatively homogeneous economic bloc, the BRICS Plus framework encompasses economies with varying levels of financial development, energy dependence, and geopolitical exposure (Belguith et al., 2025; Kumar et al., 2021). This diversity provides an ideal setting for examining cross-market heterogeneity in risk transmission and asset behavior during periods of global financial stress.

Accordingly, the main objective of this study is to investigate whether crude oil and natural gas can act as effective diversifiers, hedging instruments, or safe-haven assets for BRICS Plus stock markets during major global crises. Rather than assuming a uniform protective role across shocks, the study evaluates the performance of energy commodities under three distinct crisis environments: the COVID-19 pandemic, the Russia–Ukraine conflict, and the SVB collapse.

The empirical findings reveal several important insights. First, crude oil exhibits strong diversification properties during tranquil periods and functions as a crisis-contingent safe haven during major systemic shocks, particularly in Russia, India, and China, where it provides substantial downside risk protection. Second, natural gas exhibits more stable but less crisis-sensitive behavior, primarily serving as a consistent hedge and diversifier, with stronger performance observed in markets such as Brazil and Egypt. Third, the results highlight significant cross-market heterogeneity across BRICS Plus economies, reflecting differences in energy exposure, economic structure, and financial integration. Overall, these findings suggest that the risk-mitigation role of energy commodities is highly context-dependent and varies across crises and markets.

This study contributes to existing literature in several ways. First, it extends the safe-haven literature by providing a comparative analysis of crude oil and natural gas across multiple global crises, highlighting that their protective roles are crisis-specific rather than universal. Second, by focusing on the heterogeneous BRICS Plus economies, the study reveals important cross-market asymmetries in the hedging effectiveness of energy commodities. Third, it contributes methodologically by employing a time-varying copula framework to capture dynamic dependence structures between energy commodities and stock markets under extreme market conditions. These contributions offer valuable insights for both investors and policymakers seeking to design resilient portfolio strategies in emerging and frontier markets.

To achieve these objectives, the study employs a time-varying copula approach to capture the dynamic dependence structure between BRICS Plus stock indices and energy commodities across the three major crisis periods (Akhtaruzzaman et al., 2023; Dammak et al., 2024). This framework allows the strength and direction of dependence to vary over time and across markets, providing a more comprehensive assessment of hedging, diversification, and safe-haven properties.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on safe-haven assets and commodity-stock market linkages. Section 3 presents the data and research methodology. Section 4 reports the empirical results. Section 5 discusses the portfolio implications, and Section 6 concludes with policy and investment recommendations.

2. Literature Review

Black swan events like COVID-19, the Russia-Ukraine conflict, and the SVB collapse are extreme and infrequent occurrences that generate substantial panic and instability in financial markets (Snene Manzli & Jeribi, 2024a,b,c). Global stock markets have experienced extreme fluctuations since the onset of the pandemic, plunging to lows during the initial pandemic declaration in March 2020 (Zhang et al., 2020; Snene Manzli & Jeribi, 2024a,b), and witnessing sharp declines in stock prices during the more recent Russia-Ukraine conflict (Ahmed et al., 2022; Fakhfekh et al., 2023; Snene Manzli & Jeribi, 2024a,b) and the SVB collapse (Aharon et al., 2023; Snene Manzli & Jeribi, 2024a,b). Consequently, stock market investors should reassess their strategies for allocating capital, incorporating safe-haven assets into their stock portfolios to mitigate the significant risks of downside exposure they face.

Since Baur and Lucey's (2010) fundamental work, the safe haven literature has evolved to include a wide range of financial assets and methodologies. Early study concentrated mostly on precious metals and traditional financial instruments, notably gold (Baur & Lucey, 2010; Jeribi & Snene Manzli, 2020; Snene Manzli & Jeribi, 2024a), bonds (Hager, 2017; Robiyanto, 2018), currencies (Salah et al., 2023), and digital assets (Ghorbel et al., 2022; Widjaja et al., 2023; Maouchi et al., 2024; Snene Manzli & Jeribi, 2024a,b). Despite this breadth, many recent studies indicate that these traditional safe havens may exhibit poor protective properties under certain crises (Umar et al., 2023) due to financialization and increased co-movement with equity markets (Ali et al., 2020; Kyriazis, 2022).

In parallel, a significant body of research has focused on the interconnectedness and spillover effects of commodities and financial markets, reflecting deeper market integration and increasing commodity financialization (Belguith et al., 2025). Recent studies (such as Umar et al., 2024; Hanif et al., 2024; Malhotra et al., 2025) show that commodity markets, including oil, gas, and metals, have a time-varying connection with stock markets during crises that intensifies during extreme market stress. This highlights the increasing importance of commodities as potential hedges or safe havens during turbulent periods, motivating our focus on energy markets in BRICS Plus.

Ghallabi et al. (2025) examine correlations and risk spillovers between crude oil, gold, a global commodity index, and emerging stock markets using an ADCC-CoVaR approach. Their findings show that downside risk spillovers are stronger than upside ones during crises like COVID-19 and the Russia-Ukraine conflict, while gold exhibits minimal spillovers, confirming its safe-haven role. Crude oil spillovers remain relatively stable, providing useful insights for portfolio risk management in volatile markets. This study supports our analysis of context-dependent safe-haven properties of energy commodities in emerging markets.

Although commodity safe-haven features have typically received less attention than those of financial assets, few studies have explored this specific commodity behavior. For instance, Liu et al. (2020) employ the Asymmetric DCC model to examine crude oil's role as a safe haven, hedge, and diversification tool for traditional currencies. Their results underscore minimal or negative correlations, particularly during times of crisis, under-

scoring crude oil's distinct roles as a safe haven and hedge for major currencies. Robiyanto (2017) employs a GARCH methodology to assess commodity market instruments, including West Texas Intermediate (WTI) crude oil, examining their effectiveness as hedges and safe havens for stock markets in Southeast Asian countries such as Indonesia, Singapore, Malaysia, the Philippines, and Thailand. The results indicate that WTI has the potential to serve as a strong safe haven for most Southeast Asian capital markets. Using copula methodologies, Elie et al. (2020) investigate the potential role of crude oil as a safe haven against severe declines in clean energy stock indices. Their empirical findings indicate that crude oil exhibits limited safe-haven properties for clean energy indices, even relative to gold.

Ali et al. (2020) investigate the diversification, hedging, and safe-haven capabilities of commodities against various international stock markets, indicating their significant hedging and safe-haven potential. Jeribi and Snene Manzli (2020) examine how crude oil can act as a hedge and a safe haven for Tunisian stock prices during the COVID-19 pandemic. Their study demonstrates its role as a safe haven asset. More recent research extends this analysis to pandemic-related interventions. For instance, Yousaf et al. (2025) show that COVID vaccinations positively affect oil and sectoral equity indices, while bond effects vary, illustrating the differential responses of commodities and financial assets to policy measures. Kyriazis (2022) explores the influence of the Russian-Ukrainian military conflict on the performance of energy commodities. Their findings affirm the safe-haven characteristics of commodities, indicating that natural gas is the most advantageous choice.

Yang et al. (2024) employ quantile-based methods to argue that crude oil serves as a diversifying asset during equity market shocks. Hasan et al. (2022) assert that crude oil serves as a safe haven against uncertainties in the cryptocurrency market. Using a quantile-on-quantile regression (QQR) approach, Naeem et al. (2022) investigate the safe-haven and hedging capabilities of crude oil and gold against other commodities. Their findings indicate that oil acts as a safe haven for metals and agricultural commodities and demonstrates greater hedging effectiveness than gold. Using quantile regression and cross-quantilogram approaches, Mujtaba et al. (2024) analyze the hedging and safe-haven attributes of commodities, including energy commodities, in both the broader and sector-specific equity markets of the United States and China. Their results suggest that energy commodities exhibit safe haven characteristics for the information technology and healthcare sectors. Mensi et al. (2025) further show that oil-stock spillovers intensify in extreme market states, but diversification strategies remain effective across market phases, demonstrating context-specific hedging opportunities. Gubareva et al. (2025) investigate oil, AI, clean technology, and traditional markets, revealing that oil and the USD consistently absorb net risk, while stocks, AI, and clean tech transmit risk, emphasizing oil's role as a buffer during extreme shocks.

Majumder (2022) assesses the hedging and safe-haven properties of gold, cryptocurrencies, and commodities with respect to Indian stocks during the COVID-19 pandemic. The results suggest that only crude oil, natural gas, and metals exhibit safe haven qualities for these equities. Tarchella et al. (2024) investigate how crude oil functions as a diversifier, a hedge, and a safe haven against the G7 stock market indices amid the COVID-19 pandemic. Their findings affirm crude oil's effectiveness as a hedge during these crises.

Diaconășu et al. (2022) study the impacts of the Russia-Ukraine conflict on global commodities and stock markets. Their research indicates that oil is the only asset exhibiting safe-haven characteristics for investors during the initial stages of the conflict. Applying correlation and rolling correlation methods, Gulljord and Miron (2023) find that Brent crude oil and natural gas serve as diversifying assets for the US, Norwegian, Danish, and Swedish stock markets during the COVID-19 pandemic and the Russia-Ukraine conflict.

From the aforementioned studies, it is clear that the literature on the safe-haven potential of energy commodities remains underdeveloped, particularly with respect to BRICS stock market indices. While considerable research has examined safe-haven assets such as gold, bonds, currencies, and digital currencies in relation to stock market volatil-

ity, there has been limited investigation into how energy commodities, such as oil and natural gas, perform in providing stability during market downturns in the BRICS economies. In this regard, we are trying to fill this gap in the literature through this paper.

3. Research design and econometric methodology

3.1. Research design

This study aims to examine the diversification, hedging, and safe haven properties of crude oil and natural gas against emerging asset categories. In this context, we adopt a time-varying copula approach to analyze the evolving dependence structure between the stock market indices of BRICS Plus countries (BVSP, RTSI, MERV, SSE, BSE30, JTOPI, TASI, EGX30, and ADX) and WTI crude oil and natural gas. The data for all assets cover the period from January 4, 2016, to January 5, 2024.

To investigate the dependency structure, we follow a three-step methodology. First, we model the return series' margins by fitting AR(1) models with asymmetric GARCH-type volatility and Student-t innovations to each time series. The autoregressive component captures short-term mean dependence, while the GARCH-type specification models conditional volatility dynamics. Then, fitted residuals are extracted from all series, which are used as input for copula models. To handle challenges like autocorrelation, non-normality, nonlinearity in dependence, and shock asymmetry, we use a Fractionally-Threshold /Integrated /Exponential /Component-wise GARCH model with parameters (p, d, q). This model is designed to handle shock asymmetry and persistence simultaneously, considering ARCH, long memory, and threshold effects. We select the best model based on AIC, BIC, HQ, and estimation significance.

In the second step, the fitted residuals are employed to estimate a dynamic Student-t copula, allowing the dependence parameter to evolve over time and better capture time-varying co-movements and tail dependence. This dynamic specification constitutes our baseline model for the analysis.

For robustness checks, we additionally estimate three alternative static copula models: Gaussian, Gumbel, and Student-t using the same residuals (Appendix). The optimal static specification is selected based on the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Across all bivariate combinations, the static Student-t copula consistently provides the lowest AIC and BIC values, confirming its superior goodness-of-fit and stronger ability to capture extreme dependence. These results demonstrate that our findings are not sensitive to the copula specification and further support the appropriateness of the Student-t copula framework.

Moreover, to examine the sensitivity of the results to alternative crisis windows, the full sample is divided into two sub-periods: a pre-crisis phase (January 4, 2016 – December 31, 2019) and a crisis phase (January 1, 2020 – January 5, 2024), which includes major global disruptions such as the COVID-19 pandemic and subsequent geopolitical tensions. The copula analysis is re-estimated for each sub-period, and the results remain qualitatively consistent across different market regimes. Finally, we use the time-varying GARCH-COPULA dependence parameter to calculate the dynamic Hedge ratio (Beta) and Effectiveness efficiency (HE) for each bivariate portfolio comprising BRICS PLUS Indices and WTI or GAS.

3.2. Econometric methodology

3.2.1. Time-varying t-Student copula

Let us consider r_a and r_b BRICS PLUS stock returns indices and r_d for WTI/GAS. Their respective marginal conditional cumulative distribution functions are $u_{a,t} = G(r_{a,t}|\varphi_{t-1})$ and $u_{d,t} = G(r_{d,t}|\varphi_{t-1})$ whereas φ_{t-1} reflects the past information. The conditional copula function $C_t(u_{a,t}; u_{d,t}|\varphi_{t-1})$ can be formulated using both time-varying cumulative distribution functions. The bivariate conditional cumulative distribution func-

tions of random variables r_a and r_d , as extension of Sklar's theorem. Such functions can be written as follows:

Let us consider r_a and r_β BRICS PLUS stock returns indices and r^s for WTI/GAS. Their respective marginal conditional cumulative distribution functions are $u_{a,t} = G(r_{a,t} | \varphi_{t-1})$ and $u_{d,t} = G(r_{d,t} | \varphi_{t-1})$, whereas φ_{t-1} reflects the past information. The conditional copula function $C_t(u_{a,t}, u_{d,t} | \varphi_{t-1})$ can be formulated using both time-varying cumulative distribution functions. The bivariate conditional cumulative distribution functions of random variables r_a and r_β , r^s , as extension of Sklar's theorem, such functions can be written as follows:

$$F(r_{a,t}; r_{c,t} | \varphi_{t-1}) = C(r_{a,t}; r_{d,t}) \quad (1)$$

The conditional joint density can be written as follows:

$$f(r_{a,t}; r_{d,t} | \varphi_{t-1}) = \partial F(r_{a,t}; r_{d,t} | \varphi_{t-1}) / \partial r_{a,t} \partial r_{d,t} = C_t(r_{a,t}; r_{d,t} | \varphi_{t-1}) \times g_{a,t}(r_{a,t} | \varphi_{t-1}) \times g_{d,t}(r_{d,t} | \varphi_{t-1}) \quad (2)$$

where $C_t(r_{a,t}; r_{d,t} | \varphi_{t-1}) = \partial^2 C_t(u_t, v_t | \varphi_{t-1}) / \partial u_t \partial v_t$ is the conditional copula density function and $g(\cdot)$ is the density function corresponding to $G(\cdot)$. The likelihood function issued from the previous equation can be written as follows:

$$L_{a,d}(\Phi) = L_a(\Phi_a) + L_d(\Phi_d) + L_{cop}(\Phi_{cop}) \quad (3)$$

where Φ_a and Φ_d are the parameter vectors of marginal distributions of BRICS PLUS and WTI or GAS returns, respectively, and Φ_{cop} is the vector of parameters in the copula function. The change in the parameters of the time-varying copulas is governed by an evolution equation. With the Gaussian and Student-t bivariate copulas, the evolution of the linear dependence parameter ρ_t follows an ARMA (1, q)-type process (Patton, 2006):

$$\rho_t = \lambda(\varphi_0 + \varphi_1 \rho_{t-1} + \varphi_2 \frac{1}{q} \sum_{j=1}^q \varphi^{-1}(u_{t-j}) \varphi^{-1}(v_{t-j})) \quad (4)$$

Where $\lambda = (1 - e^{-x})(1 - e^{-x})^{-1}$ is the modified logistic transformation, which ensures that ρ_t belongs to $[-1, 1]$. This implies that a constant parameter determines the dependence parameter φ_0 , the explanatory factor of the historical correlation as scaled by φ_1 , and the average product of the last q observations of the transformed variables, φ_2 .

3.2.2. Optimal Hedging Ratio (HR) and Hedging Effectiveness (HE)

After examining the Time-Varying Student t copula, we evaluate the diversification potential of Bitcoin and gold across the stock markets of BRICS Plus countries. It is important to distinguish between safe havens, diversifiers, and hedging instruments, as each serves a different function. Following the seminal work of Baur and Lucey (2010), a safe haven is an asset that preserves or increases its value during periods of market stress, providing protection when other assets experience losses. A diversifier is an asset that reduces overall portfolio risk by being imperfectly correlated with other holdings, contributing to smoother returns over the long term. Finally, a hedging instrument is employed to offset a specific risk exposure, such as fluctuations in commodity prices or interest rates, through targeted risk mitigation strategies. Clearly distinguishing these roles ensures precise interpretation of empirical results and informs appropriate investment strategies. We dynamically compute the optimal portfolio allocations, hedge ratios, and effectiveness for paired portfolios. These portfolios are structured by taking a short position in WTI or GAS alongside a long position in stock indices. The hedge ratio (HR) ($\beta_{BP,H,t}$), as defined by Kroner and Sultan (1993), indicates the amount of diversification potential required in a short position to hedge one unit of the stock indices in a long position. This measure also signifies the hedging efficiency of the BRICS Plus indices. Therefore, a higher $\beta_{BP,H,t}$ indicates stronger hedging of the stock assets and suggests a higher cost associated with hedging one unit of the indices. Equation 5 outlines the hedge ratio for a single unit of the index at time t.

$$\beta_{BP,H,t} = \frac{h_{BP,H,t}}{h_{H,t}} \quad (5)$$

where $h_{BP,t}$ and $h_{H,t}$ signify the volatility of the BRICS Plus indices and their hedging capabilities, respectively. The hedge ratio is determined by dividing the covariance of the BRICS Plus and the diversification potential by the variance of the diversification potential. Following the hedge ratio calculation, we derive the optimal portfolio allocations. For binary portfolios consisting of BRICS Plus/H, the optimal weight of BRICS Plus at time t in the portfolio, denoted as $w_{BP,H,t}$, is formulated according to the method outlined by Kroner and Ng (1998).

Finally, to gain a more comprehensive understanding of the hedging capabilities of the BRICS Plus stock returns, we calculate the hedging effectiveness (HE):

$$HE = \frac{\text{var}(\text{unhedged}) - \text{var}(\text{hedged})}{\text{var}(\text{unhedged})} \quad (6)$$

where $\text{var}(\text{unhedged})$ and $\text{var}(\text{hedged})$ represents the variance of the unhedged and hedged portfolios, a higher HE indicates higher hedging efficiency and a more significant risk reduction (Charfeddine et al., 2020).

4. Data description and descriptive statistics

4.1. Data description

The empirical research involves daily observations of BRICS Plus stock market indices (Brazil (BVSP), Russia (RTSI), India (BSE30), China (SSE), South Africa (JTOPI), Argentina (MERV), Saudi Arabia (TASI), Egypt (EGX30), and the United Arab Emirates (ADX)), along with WTI crude oil and natural gas prices, sampled from January 4, 2016, to January 5, 2024. The data was collected from the Datastream database. The daily closing price data is converted into a daily return series for analysis as follows:

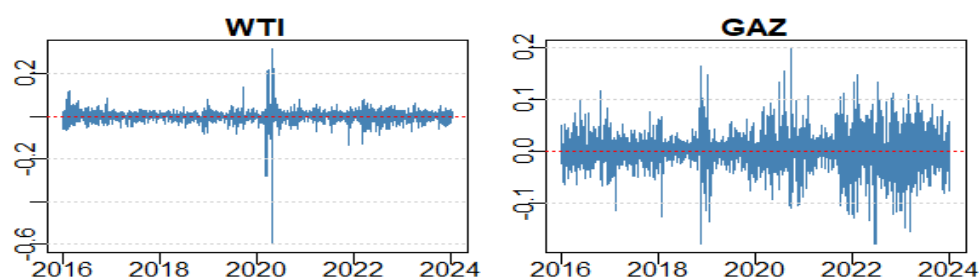
$$r_{it} = \log\left(\frac{p_{i,t}}{p_{i,t-1}}\right) \quad (7)$$

Where $p_{i,t}$ represents the closing price of asset i at time t .

4.2. Descriptive statistics

Figure 1 illustrates the dynamics of these series over time, confirming that the return series are stationary, while Figure 4 indicates that the price series are not stationary.

Figure 1. Time Varying Return Series



Strong geographical co-movements are evident throughout the entire series' return patterns. Notably, all series are platykurtic except for Russia (RTSI), Argentina (MERV), and WTI, which display significant leptokurtic behavior, suggesting they are almost linearly increasing and have different underlying dynamics compared to the other series under study. Furthermore, all series show a peak in early 2020, except for the Russian Trading System Index (RTSI). Specifically, WTI and MERV exhibit greater differences in extreme return values than the other BRICS Plus indices. For example, RTSI shows a clear decrease from -1.8% to -48% on February 24, 2022, reaching a minimum of -0.4829 while

WTI crude oil reaches -0.6016. The descriptive statistics for the entire series are depicted in the following table. Table 1 presents the descriptive statistics related to the return series.

Table 1: Descriptive statistics

	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Q(20)	Q2(20)
BVSP	5.543E-04	0.1302282	-0.1599383	0.0155061	-1.200***	17.501***	26889.72***	79.9***	2331.03**
RTSI	0.0001796	0.2320443	-0.4829211	0.0210555	-5.783***	143.85***	1794627***	41.23**	121.67***
SSE	0.0004997	0.0612991	-0.0799438	0.0105484	-0.721***	7.303***	4775.2***	32.8***	230.58***
BSE	-5.764E-05	0.0674683	-0.1410174	0.0104259	-1.688***	24.298***	51853.76***	58.8***	1059.7***
JTOPI	0.0002066	0.0790710	-0.1045042	0.0119265	-0.500***	7.091***	4418.918***	27.5***	1547.7***
MERV	0.0021853	0.1240405	-0.4769221	0.0261094	-3.276***	56.938***	283043.5***	11.708	18.7**
TASI	0.0002719	0.0683146	-0.0868458	0.0100200	-1.116***	10.458***	9852.697***	75.1***	750.35**
EGX	0.0006161	0.0893940	-0.0904208	0.0128647	-0.219***	6.063***	3184.317***	96.0***	404.42***
ADX	0.0003946	0.0807617	-0.0840626	0.0096079	-0.325***	17.408***	26149.49***	81.3***	2304.0***
WTI	0.0003471	0.3196337	-0.6016758	0.0325614	-2.944***	72.859***	460401.0***	67.5***	386.2***
GAS	9.4387e-05	0.1979844	-0.1806609	0.0369604	-0.114**	2.717***	640.579***	27.0***	317.76***

The average return for BSE Sensex 30 is negative, while the average returns for all the other BRICS Plus series are positive. The series with the highest standard deviations are GAS and WTI, followed by the MERV and RTSI indices. The BSE and SSE stock market indices have relatively low standard deviations of 0.0104259 and 0.0105484, respectively, indicating lower volatility than the Russian and Brazilian markets. Investors may perceive these markets as less risky with respect to price fluctuations. The Jarque-Bera test for normality rejects the null hypothesis of normality for the series. The Ljung-Box test results on the residuals and their squares suggest multicollinearity in the squared residuals. This multicollinearity indicates that the series exhibits heteroscedasticity, implying the presence of ARCH effects.

5. Empirical results and discussion

5.1. Empirical results

5.1.1. FT/E/GARCH Models Estimation Results

Based on the information criterion, we chose the appropriate GARCH model. The AR(1)-EGARCH and TGARCH models prove suitable for all series, as they do not exhibit any autocorrelation (with Q(20) and Q2(20) being non-significant) and do not highlight any ARCH effect. However, for MERV, EGX, and ADX, the Standard-GARCH model is the most appropriate for capturing volatility dynamics in financial time-series returns during this period.

The ARCH effects, with serial correlation throughout the series, indicate return-volatility persistence, as observed in the return series, thereby justifying the use of non-linear GARCH models such as Exponential-GARCH and Threshold-GARCH. Consequently, to incorporate the financial leverage effect on volatility through the lens of asymmetric shocks, we opted for the AR(1)-EGARCH model and the AR(1)-TGARCH model, including an asymmetrical parameter. This approach allows us to capture both the impact of negative versus positive shocks and the magnitude of these shocks on volatility.

The stock returns of China, India, South Africa, and Russia are modeled using E-ARCH models to capture both asymmetric-shock and financial leverage effects. As indicated in Table 2, the leverage-effect coefficient (LEV) is positive and statistically significant for all these stock indices. This often implies that bad news or negative events have a larger impact than good news or positive events. A positive coefficient typically suggests that negative shocks increase volatility less than positive shocks, which contrasts with the positive coefficient reported in our results. The positive and statistically significant leverage-effect coefficient (LEV1) observed indicates a notable leverage effect.

Table 2. Univariate Conditional Mean and Volatility Model Estimation for BRICS Plus Stock Indices, WTI, and Natural Gas

	A	AR(1)	C	ARCH(1)	GARCH(1)	Tail	Lev	Eta1
BVSP	0.000979***	-0.03215	0.0000***	0.0699***	0.88958***	7.27342***	-	0.9898***
RTSI	0.001009***	0.030455**	0.000005***	0.078695***	0.901302***	5.591577***	-	0.4184***
BSE	0.000647***	0.092742***	-0.22889***	-0.11364***	0.976375***	6.497749***	0.11859***	-
SSE	0.000291*	-0.017816	-0.28806***	-0.056261**	0.969078***	3.877567***	0.189944***	-
JTOPI	0.000142	0.033851	-0.30389***	-0.12496***	0.96666***	8.009978***	0.12364***	-
MERV	0.002238***	0.126151***	0.000025***	0.186489***	0.782243***	6.535997***	-	-
TASI	0.000741***	0.187018***	0.000005*	0.204416***	0.749132***	5.481648***	0.26882***	-
EGX	0.000639*	0.173765***	0.000007***	0.112676***	0.849418***	4.792960***	-	-
ADX	0.000401***	0.047022*	0.000005***	0.207102***	0.746211***	4.069927***	-	-
WTI	0.001172**	0.002884	0.000752***	0.092562***	0.897170***	5.754118***	-	0.63084***
GAS	0.000747	-0.02631	0.000208**	0.079264***	0.93397***	7.715452***	-	-0.17500*

Notes: *, ** and *** reflect the significance level at 10%, 5% and 1%

This perhaps puzzling result can be explained by the fact that the BSE, SSE, JTOPI, and RTSI stock markets are not dominated by uninformed investors but rather by informed investors. Consequently, these stock market investors may be less prone to herding and more likely to act as contrarians, which helps explain the differing estimates and behavior of the four indices. This suggests that they respond more strongly to both positive and negative news than the other BRICS Plus returns do.

Additionally, parameter estimates for different GARCH models show positive, significant coefficients (p-values << 5%) on the GARCH term, indicating that stock market news about past volatility has explanatory power for current volatility. The T-GARCH model, in turn, appears to capture both the asymmetric and magnitude-shock effects. As indicated in Table 2, the coefficient (Eta) is positive and significant for BVSP, RTSI, and WTI. A positive coefficient signifies that negative shocks have a larger impact on volatility than positive shocks. However, this coefficient is negative and significant for oil volatility, suggesting that price movements driven by less-informed investors may contribute more to oil price instability. Additionally, the tail parameter is statistically significant across all series, suggesting that the Student-t distribution is appropriate.

From the above, the stock returns of China, India, South Africa, and Russia exhibited significant leverage-effect coefficients (LEV), indicating a pronounced impact of negative shocks relative to positive ones. This suggests that negative events have a greater influence on volatility than positive ones in these markets, potentially because informed investors respond in the opposite direction to market movements. Moreover, all series showed positive and statistically significant GARCH coefficients, underscoring that past volatility news affects current volatility. Notably, the T-GARCH model captured both asymmetric and magnitude-shock effects, with significant coefficients (Eta) observed for BVSP, RTSI, and WTI. The statistical significance of the tail parameter across all series further supports the appropriateness of the Student-t distribution for modeling extreme events in the data.

5.1.2. Dynamic GARCH-Copula Approach: Crude Oil/Natural Gas and BRICS PLUS Time-Varying Dependencies

The copula selection procedure is based on comparing alternative information criteria following the estimation of three competing static-copula families: Gaussian, Gumbel, and Student-t across the two identified sub-periods (Appendix). The preference for the Student's t-copula is due to its ability to handle heavier tails compared to a normal (Gaussian) distribution, indicating a higher likelihood of extreme events. Its dynamic nature also makes it more adaptable for modeling tail dependencies.

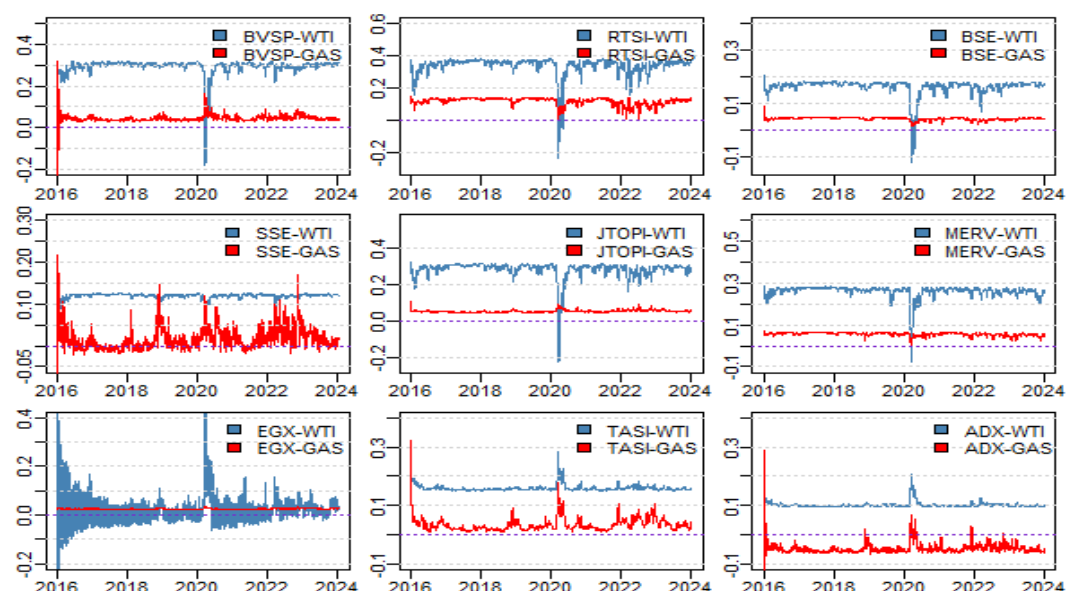
This approach considers important characteristics of financial returns, such as volatility clustering, time-varying volatility, and short- and long-run dependence behavior. It improves the computation of residuals, making them suitable for further statistical anal-

yses because they are approximately independent and identically distributed (i.i.d.), as noted by Gregoire et al. (2008).

To address potential fat tails in the error term, the Student's t-distribution is used instead of the Gaussian distribution often employed in empirical studies. Additionally, the Student's t-dependence structure allows for joint extreme movements, regardless of the marginal behavior of the individual random variables. These variables are uniformly distributed and obtained by transforming the cumulative distribution of the two standardized residual time series (x and y), which are derived from estimating the appropriate ARIMA-GARCH model.

This analysis enables us to assess a variety of structural dependencies; we present the most significant ones and interpret the figures in relation to periods of crises and crashes aligned with significant global economic events. Figure 2 illustrates the dependencies between BRICS Plus-WTI/GAS pairs for comparative analysis.

Figure 2: Time-varying dependence parameter from the Student-t copula for the pair BRICS PLUS – WTI/GAS



This figure illustrates the evolution of the dynamic dependence parameters estimated using a Student-t copula, capturing both tail dependence and nonlinear co-movements between BRICS Plus stock market indices and energy commodities (WTI crude oil and natural gas). Variations in the dependence structure reflect changing market conditions and crisis episodes, indicating periods of strengthened or weakened linkages that are relevant for portfolio diversification, hedging effectiveness, and safe-haven assessment.

The findings indicate that, generally, BRICS Plus' dependency on WTI is higher than their dependency on GAS. Dependencies between the series change over time and reach extreme values in specific periods. During events with significant global economic impact, such as COVID-19 (early 2020), the Russia-Ukraine conflict (post-February 2022), and the SVB bankruptcy (March 2023), drastic changes can be observed in the dependency paths.

During the COVID-19 pandemic (early 2020) and the Russia-Ukraine conflict (post-February 2022), dependency shocks are more pronounced with WTI compared to natural gas. Particularly in the post-COVID period, a significant drop is observed, with values turning negative for the time-varying dependence copula, namely for BVSP, RTSI, SSE, BSE, JTOPI, and MERV. For ADX, TASI, and EGX, the figures show upward peaks (by +0.6). These results suggest that WTI acts as a strong diversifier in normal times, a safe haven during early 2020 (post-COVID-19), and a hedging instrument in the post-February 2022 period (Russia-Ukraine conflict). In contrast, for Saudi Arabia, Emirates, and Egypt,

WTI is recorded as a strong diversifier only during the COVID-19 period. During the SVB bankruptcy (March 2023), results show that WTI serves as a diversifier, with its safe-haven ability observed primarily for Russia, India, and notably China. These findings are consistent with Ali et al. (2020), Jeribi and Snene Manzli (2020), Diaconășu et al. (2022), and Mujtaba et al. (2023), who endorse crude oil's safe-haven status for stock markets. Our results also corroborate those of Yang et al. (2024) and Gulljord and Miron (2023), who support oil's diversification benefits relative to stock markets.

According to the time-varying dependence copula for BRICS Plus with natural gas, the degrees of dependence vary over time, as shown in these figures. The correlation between natural gas and all BRICS Plus indices appears to fluctuate, sometimes decreasing, even during bear market periods. In fact, natural gas can be considered a diversifier and a hedging instrument in normal times and during the crises of 2022 and 2023 for almost all stock indices. For the GAS-RTSI/MERV/BSE pairs, natural gas acts as a diversifier in normal periods and as a hedging asset during downturns, especially during the Russia-Ukraine conflict and SVB bankruptcy events. This explains the low sensitivity of natural gas to economic shocks while retaining its ability to maintain the same dependency structure with the majority of stock indices, highlighting its diversification properties. This finding is consistent with Gulljord and Miron (2023), who discovered that natural gas serves as a diversifier. Conversely, the average correlation with ADX and TASI indices is close to zero or even slightly negative, indicating low dependency. This suggests unique investment and hedging opportunities when constructing investment portfolios, supporting the findings of Kyriazis (2022).

Table 3 presents the dynamic dependence parameters for the BRICS Plus-WTI/GAS pairs using the GARCH-Copula approach. These relationships tend to be unstable, fluctuating between negative and positive values over the study period. This variability may indicate the presence of both low and high-volatility regimes, which influence the correlations between these assets. These empirical findings prompt further analysis of the advantages and portfolio diversification benefits of these combinations. The weight parameter (w) represents the contribution of each asset to the copula. A positive value indicates a positive contribution, while a negative value suggests a negative contribution. The weight's significance reflects the strength of the relationship. The parameters (W and w_2) pertain to BRICS Plus and WTI/GAS, respectively.

The parameters Beta1, Beta2, Beta3, and Beta4 measure the tail dependence between the assets. A negative value for Beta1 indicates negative tail dependence, meaning extreme events in one asset are associated with opposite extreme events in the other asset. A positive value indicates positive tail dependence, in which extreme events in one asset are associated with similar extreme events in the other.

In line with the time-varying copula figure, our empirical results on copula parameters suggest that the stock markets of BRICS Plus countries are influenced by both WTI and GAS, with varying degrees of dependency. Positive relationships indicate that stock market movements are influenced in the same direction as WTI, while negative relationships indicate the opposite direction. This information can help investors understand how changes in commodity prices may affect these stock markets and potentially hedge their portfolios accordingly.

The weight (w) for BVSP-WTI is insignificant, indicating a relatively negligible relationship, while the contribution of GAS to the BVSP-GAS copula is significant, with a high coefficient. The Beta4 coefficient for BVSP-GAS is significantly high at 4.9012, indicating strong tail dependence between the Brazilian stock index and natural gas. This suggests that the role of hedging and safe-haven properties of natural gas is more consistent than those of WTI for the BVSP stock market index.

Conversely, for the Russian stock market, the results show non-significant copula parameters with natural gas, suggesting no structural dependence between the RTSI and gas. However, there is a significant negative relation between this index and WTI, reflecting the influence of crude oil. Indeed, the parameters Beta3 and Beta4 have significant

negative coefficients. Thus, WTI can be considered a strong hedging instrument in normal times and a robust safe haven during crisis events for the RTSI stock market. For instance, investors could use crude oil contracts to hedge against potential downturns in the Russian stock market. These findings are in line with Naeem et al. (2022) and Tarchella et al. (2024), who support the perfect hedging ability of crude oil, and with Ali et al. (2020), Jeribi and Snene Manzli (2020), Diaconășu et al. (2022), Hasan et al. (2022), Naeem et al. (2022), Majumder (2022), and Mujtaba et al. (2023), who endorse crude oil's safe haven ability.

Contrary to RTSI, the Chinese stock index (SSE) shows a non-significant relationship with crude oil (WTI) but a negative and significant dependence on natural gas. Turning to tail dependence, there is evidence of significant low negative tail dependence between oil price changes and China's stock market returns, whereas the relationship between stock market returns and natural gas changes exhibits insignificant tail dependence. For instance, the tail dependence indicates extreme co-movements, meaning that extreme oil price events are associated with opposite movements in China's stock market returns, whereas the introduction of natural gas in the SSE stock market has no mitigating effect on portfolio risk. Thus, natural gas acts as a hedge for SSE, and WTI is considered a safe-haven asset during extreme events.

For the Indian market, the oil and gas copulas show similar empirical results. Gas appears to have more consistent and significant effects than WTI, suggesting that it may not act solely as a hedge but also as a safe haven in stressful times. However, for the South African stock market index, the results show no significant dependencies on either WTI or gas. Thus, there is no discernible dependence structure between crude oil and natural gas with South Africa, either in normal times or during crisis periods. For MERV, WTI is recorded as a safe-haven asset. Indeed, the tail dependence coefficients are negative and significant for the copula between WTI and MERV. The hedging and safe-haven ability of WTI is also evident in TASI and ADX. However, natural gas is a better hedging option for the Egyptian stock market (EGX) (Kyriazis, 2022).

In summary, significant global economic events lead to drastic changes in dependency patterns, highlighting WTI's pivotal role as a diversifier, safe haven, and hedge instrument at various times. GAS also proves its worth as a diversifier and a hedging instrument, especially for certain stock markets such as BVSP, EGX, and SSE. This phenomenon could be attributed to factors such as the country's oil position, oil consumption, and the significance of oil to its national economy, as suggested by Liadze et al. (2022) and Snene Manzli and Jeribi (2024c). For instance, Saudi Arabia (TASI) and the UAE (ADX) exhibit higher levels of oil consumption, production, and exports than other countries.

The time-varying nature of these dependencies, especially the significant increases and decreases during global events, underscores the need for developing a dynamic portfolio diversification strategy.

5.1.3. Portfolio Implications of Crude Oil / Natural Gas BRICS Plus interdependence

In this subsection, we analyze binary portfolios comprising the stock market indices of BRICS Plus countries, along with WTI crude oil and natural gas (GAS), to uncover deeper investment insights. This analysis focuses on determining hedge ratios, optimal portfolio allocations, and the effectiveness of hedging strategies for such portfolios. Figures 4 and 5 illustrate the dynamic hedge ratios of these binary portfolios over time. This graphical analysis allows us to evaluate various strategies to assess the effectiveness of WTI and GAS in mitigating risks for BRICS Plus countries' investors, especially following financial crises during the studied period. To be effective, we interpret the figures in relation to periods of economic crisis for each binary portfolio.

Table 3: Time-Varying Student-t Copula Parameters Estimation Results for BRICS PLUS Indexes-WTI/GAS pairs

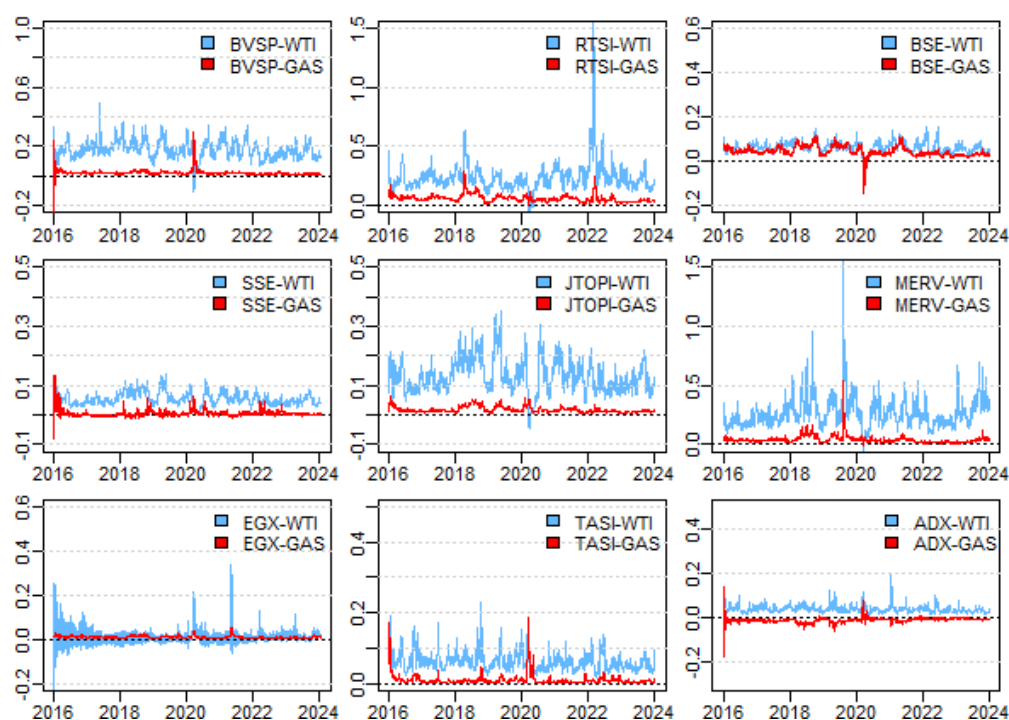
Panel B: BRIC PLUS -WTI/GAS							
BVSP / WTI				BVSP / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
w	0.6430	w2	-0.6011	w	0.1099	w2	-5.000***
Beta1	0.0685	Beta3	-0.1134	Beta1	-1.6345***	Beta3	0.0620
Beta2	-0.1008	Beta4	-0.8552	Beta2	0.1004	Beta4	4.9012***
RTSI / WTI				RTSI/ GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
w	0.9560*	w2	-1.0701***	w	0.2927	w2	-0.0583
Beta1	-0.3761	Beta3	-0.2139***	Beta1	0.0245	Beta3	-0.0665
Beta2	-0.1906*	Beta4	-0.6280***	Beta2	-0.0978	Beta4	-0.0503
SSE / WTI				SSE / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
w	0.2488	w2	0.5951	w	-0.0695	w2	-2.4249***
Beta1	0.0427	Beta3	-0.0710***	Beta1	-1.1852*	Beta3	0.0441***
Beta2	-0.0238	Beta4	-1.1998***	Beta2	0.2300	Beta4	0.3353
BSE / WTI				BSE / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
W	0.3436	w2	-1.3565***	W	0.0858	w2	-0.0862*
Beta1	0.1511	Beta3	-0.1726***	Beta1	0.1881	Beta3	-0.0509***
Beta2	-0.0675	Beta4	0.25285	Beta2	-0.0225	Beta4	0.8114
JTOPI / WTI				JTOPI / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
W	0.6428	w2	-0.2087	W	0.0789	w2	-5.000
Beta1	0.0476	Beta3	-0.0855	Beta1	0.2600	Beta3	0.0598
Beta2	-0.1219	Beta4	-0.2121	Beta2	0.0257	Beta4	4.9848
MERV / WTI				MERV / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
w	0.6007	w2	-0.0874	w	0.1316	w2	0.1348
Beta1	-0.0436	Beta3	-0.0952***	Beta1	0.0207	Beta3	-0.0490
Beta2	-0.0891	Beta4	-1.0330**	Beta2	-0.0398	Beta4	3.0889
TASI / WTI				TASI / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
w	0.3048	w2	-0.3196**	w	0.0050	w2	-4.9415***
Beta1	-0.0217	Beta3	-0.1285***	Beta1	1.2303**	Beta3	0.0635***
Beta2	0.00315	Beta4	-0.6591***	Beta2	0.0388	Beta4	4.9924
EGX / WTI				EGX / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
W	-0.0561	w2	-1.2758***	W	0.0485	w2	-0.2534
Beta1	-2.0005***	Beta3	-0.01715***	Beta1	-0.0128	Beta3	-0.0774
Beta2	0.2618***	Beta4	0.0964*	Beta2	0.0080	Beta4	-0.3200
ADX / WTI				ADX / GAS			
Coef.	Est.	Coef.	Est.	Coef	Est	Coef	Est
W	0.2468	w2	-1.1070***	W	-0.2364*	w2	2.0897
Beta1	-0.5781	Beta3	-0.1830	Beta1	-1.6924***	Beta3	-0.040
Beta2	0.0256	Beta4	-0.4701***	Beta2	0.1141	Beta4	-0.6174

Notes: *, ** and *** reflect the significance level at 10%, 5% and 1%. Table 3 reports the estimated parameters of the time-varying Student-t copula for BRICS Plus stock indices paired with WTI crude oil and natural gas. The significance and magnitude of the coefficients indicate that dependence structures are dynamic, nonlinear, and asymmetric, reflecting heterogeneous transmission of global shocks across countries and commodities. Differences across markets can be attributed to variations in energy dependence, exposure to geopolitical tensions, and integration into global supply chains.

Moreover, disparities between WTI and GAS results reflect distinct commodity market microstructures, liquidity conditions, and sensitivity to supply disruptions. These features explain why hedging and safe-haven effectiveness differs across BRICS Plus markets and crisis episodes, underscoring the importance of market-specific and crisis-dependent risk management strategies

Figure 3 displays the dynamic hedge ratios of these binary portfolios, which include BRICS Plus with WTI/GAS over time. The hedge ratio indicates how many units of oil/natural gas in a short position are required to hedge one unit of BRICS Plus countries' stock markets in a long position. A higher hedge ratio suggests better portfolio diversification and indicates the need for more WTI/GAS per unit of the stock market, pointing to lower risk-return potential. Beyond this mechanical interpretation, variations in hedge ratios also reflect structural differences in energy exposure, market integration, and the transmission of global shocks across BRICS Plus economies. From Figure 4, the empirical findings reveal that the hedge ratio of dual portfolios varies over time, and portfolios with WTI generally exhibit a higher hedge ratio coefficient (positive/negative) than those with GAS. This dominance of WTI can be economically explained by the central role of crude oil in global production networks, transportation costs, and international trade, making oil prices more directly linked to macroeconomic and financial conditions than natural gas, whose markets remain more regionally segmented.

Figure 3. Time-varying Hedge Ratio (Beta) for the pair BRICS PLUS – WTI/GAS



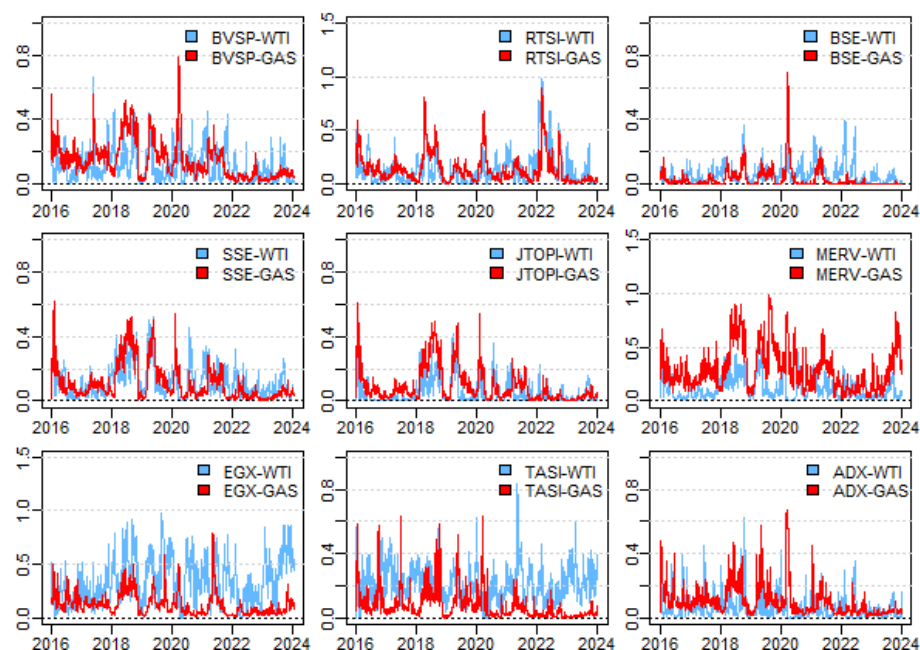
During the post-COVID period (early 2020), the hedge ratios for BSE, SSE, ADX, and EGX portfolios with WTI are consistently positive. Portfolios with Gas only take negative values with the Argentine stock market (MERV). For Argentina, Russia, and South Africa, WTI exhibits higher hedge ratios, especially for the Argentine stock market (MERV). This suggests that adding oil to a portfolio with these stock markets might be a better long-term investment strategy. These cross-market differences can be attributed to country-specific characteristics such as export dependence on energy commodities (Russia), vulnerability to external financing conditions (Argentina), and exposure to global capital flows (South Africa), which amplify the transmission of oil price shocks into equity markets. These findings are in line with Dorsman et al. (2013), who state that adding crude oil to a portfolio of stocks or bonds can enhance its risk-return trade-off. The potential of WTI as a more effective diversifier remains, offering a more effective portfolio strategy to better design risk/return preferences, especially during the Russia-Ukraine conflict (2022), nota-

bly for the Russian stock index, and during the Silicon Valley Bankruptcy (SVB) (March 2023), particularly for the Argentine and South African stock markets. From an economic perspective, geopolitical disruptions such as the Russia-Ukraine conflict directly affect oil supply expectations through sanctions, production constraints, and strategic reserves, thereby strengthening oil's hedging role relative to natural gas during periods of heightened geopolitical risk. The hedge ratio is influenced by international economic events, which change depending on the nature of the shock. The research findings align with the dependency results, indicating that utilizing a dynamic strategy may better ascertain risk/return preferences. This dynamic behavior underscores the importance of allowing hedge ratios to adjust endogenously, as static hedging strategies fail to capture shifts in investor expectations, policy responses, and commodity market liquidity during crisis episodes.

This figure illustrates the dynamic evolution of hedge ratios estimated using the multivariate GARCH framework, indicating the time-varying amounts of WTI or natural gas required to hedge a long position in BRICS Plus stock indices. Fluctuations in hedge ratios reflect changing market conditions, crisis episodes, and asymmetric volatility transmission, highlighting the non-static nature of hedging effectiveness and the importance of adaptive portfolio strategies across different economic regimes.

From Figure 4, hedging effectiveness indicates the rate of risk reduction (variance) for a one-unit portfolio in which BRICS Plus countries' indices are in a long position and WTI/GAS is in a short position. Upon overall review, hedging effectiveness fluctuates over time, exhibiting non-significant variations, especially during stable periods. However, during crises such as the post-COVID-19 period, the Russia-Ukraine conflict, and SVB, GAS is required to reduce portfolio risk in some BRICS Plus countries, sometimes not at all, whereas portfolios in these stock markets require more oil to reduce risk. This result reflects the lower liquidity and more fragmented microstructure of natural gas markets, which limits their ability to absorb global shocks compared to the highly financialized and liquid crude oil market.

Figure 4. Time-varying HE for the pair BRICS PLUS – WTI/GAS



During the COVID-19 pandemic and the Russia-Ukraine conflict, natural gas is a better choice for risk reduction and is considered a more suitable safe-haven asset for these stock market indices than WTI across all BRICS countries. This safe haven feature is well-documented for Argentina (MERV) and the United Arab Emirates (ADX) throughout the study period. In these markets, natural gas prices are more closely linked to domestic or

regional energy demand and long-term contracts, reducing their sensitivity to global financial turmoil and enhancing their stabilizing role. Conversely, the Silicon Valley Bankruptcy (SVB) disrupts these results, notably for Brazil, Russia, India, and China. The figures show that WTI remains a more effective tool for mitigating portfolio risk than natural gas. This shift can be explained by the financial nature of the SVB shock, which primarily affected global liquidity conditions and risk sentiment, channels through which oil—given its deep futures market and speculative activity—reacts more strongly than natural gas.

Regarding EGX/TASI - WTI/GAS pairs, our empirical results suggest that WTI crude oil is considered the best hedging tool in normal periods and the strongest safe haven during bear markets, especially during the Russia-Ukraine conflict and SVB events. These findings suggest that portfolios that include WTI generally exhibit greater hedging effectiveness, corroborating the findings of Naeem et al. (2022) and Tarchella et al. (2024), who support crude oil as an effective hedge.

This figure presents the dynamic hedging effectiveness of WTI and natural gas in reducing portfolio risk for BRICS Plus stock indices over time. Variations in HE reflect differences in market conditions, crisis episodes, and asymmetric responses to shocks, highlighting how the risk-reduction potential of each commodity evolves across countries and periods. The results underscore the importance of crisis-specific and market-specific strategies for portfolio risk management.

The overall findings emphasize that WTI crude oil appears to be the best hedging tool in normal periods and the strongest safe haven during bear markets, particularly during the Russia-Ukraine conflict and SVB events, compared to natural gas. These findings suggest that a dynamic strategy is crucial for determining risk/return preferences, especially during significant international economic events. The findings underscore the importance of considering these commodities in investment portfolios, as they exhibit unique characteristics that can provide opportunities for risk management and diversification. Understanding the dynamics of these dependencies can help investors make informed decisions and navigate uncertain economic conditions effectively.

5.2. Discussion

The empirical results highlight the dynamic and context-dependent nature of risk mitigation strategies involving crude oil (WTI) and natural gas (GAS) in the BRICS Plus countries' stock markets. The choice of GARCH models, including AR(1)-EGARCH and AR(1)-TGARCH, indicates the importance of capturing asymmetric shocks and leverage effects in volatility. The dynamic GARCH-Copula approach further demonstrates the time-varying dependencies between crude oil/natural gas and stock indices, emphasizing the role of these commodities in portfolio diversification and risk management. From an economic perspective, these modeling choices are particularly suited to energy markets, where negative shocks (e.g., supply disruptions or sanctions) typically generate stronger volatility responses than positive shocks, reflecting asymmetries in expectations and adjustment costs.

Crude oil acts as a strong diversifier in normal times and a reliable safe haven during crises like COVID-19, the Russia-Ukraine conflict, and the SVB bankruptcy, particularly benefiting markets like Russia, India, and China. The higher hedge ratios for portfolios with WTI during these periods align with previous studies that support crude oil's safe-haven status. Natural gas, on the other hand, consistently acts as a diversifier and hedge, demonstrating stability and positive impacts on portfolios, especially during economic downturns. This divergence can be explained by the global pricing and high financialization of crude oil markets, which transmit macroeconomic and geopolitical shocks rapidly, while natural gas markets remain more segmented and contract-based, dampening excessive price reactions.

GAS exhibits varying degrees of hedging effectiveness, with significant positive impacts on portfolios involving indices such as BVSP and EGX. The effectiveness of WTI and

GAS as risk mitigation tools is heavily influenced by global economic events, leverage and asymmetric effects, investor behavior, and regional economic factors such as oil consumption and production levels. In particular, countries with greater dependence on energy imports or exports exhibit greater sensitivity to commodity price movements, leading to heterogeneous hedge effectiveness across BRICS Plus markets. Markets dominated by informed investors, such as China and Russia, exhibit different volatility dynamics than those dominated by uninformed investors, which affects the impact of crude oil and natural gas on these markets. This may reflect differences in market depth, state intervention, and information diffusion mechanisms, which influence how energy price signals are incorporated into equity valuations. WTI's role as a diversifier and safe haven stems from its significant impact on global economic activity and its status as a major commodity in international trade, while GAS's stability and lower sensitivity to shocks make it a consistent hedge, especially during economic downturns. Moreover, the presence of deep and liquid futures markets for WTI enhances its hedging effectiveness by allowing investors to rapidly rebalance portfolios in response to crisis-induced uncertainty.

The economic position of countries influences dependency patterns, with Saudi Arabia (TASI) and the UAE (ADX) exhibiting higher oil-related dependencies due to their significant roles in the oil market. The risk mitigation effectiveness of crude oil and natural gas varies across different market conditions, with each commodity exhibiting unique characteristics that contribute to their roles as diversifiers, hedges, and safe havens. These findings underscore that hedging performance is shaped by structural economic characteristics—such as energy export intensity, fiscal reliance on hydrocarbons, and exposure to geopolitical risk—rather than by uniform commodity behavior.

Importantly, these results have several practical implications. Investors and portfolio managers can leverage the differential roles of WTI and GAS to design adaptive, crisis-specific strategies, reallocating assets toward commodities that offer stronger risk mitigation in periods of heightened uncertainty. For example, WTI may be prioritized during global crises with significant geopolitical and macroeconomic spillovers, while GAS can serve as a stabilizing hedge in more localized or supply-constrained shocks. Policymakers in energy-dependent economies can also use these insights to anticipate financial vulnerabilities arising from commodity price fluctuations and to guide macroprudential policies, such as capital requirements or portfolio diversification incentives, to enhance market stability. Overall, understanding these dynamics allows for more informed and proactive risk management in both investment and policy contexts.

Understanding these dynamics and the factors influencing their effectiveness can help investors develop more resilient and adaptive portfolio strategies, especially during periods of significant economic uncertainty.

6. Conclusion

Rare and extreme events—such as the COVID-19 pandemic, the Russia–Ukraine conflict, and the collapse of Silicon Valley Bank—have fundamentally altered risk transmission mechanisms in global financial markets. These episodes highlight the inadequacy of assuming that asset behavior is stable and uniform across crises, particularly in emerging and energy-dependent economies. This study departs from that assumption by explicitly modeling crisis heterogeneity and time-varying energy–equity linkages in the BRICS Plus context.

From a methodological perspective, this paper makes a clear contribution by jointly integrating asymmetric volatility modeling (AR(1)-EGARCH and AR(1)-TGARCH) with a dynamic GARCH-Copula framework. This combination allows us to simultaneously capture leverage effects, tail asymmetries, and evolving dependence structures between energy commodities and stock markets across distinct crisis regimes. Unlike much of the existing literature that relies on static correlations or focuses on a single shock, our approach explicitly accommodates nonlinear, crisis-specific, and market-dependent dynam-

ics, thereby offering a more realistic representation of portfolio risk during extreme events.

In terms of data and conceptual framing, the study advances the safe-haven literature by conducting a comparative multi-crisis analysis within the BRICS Plus group, exploiting cross-country heterogeneity in energy dependence, geopolitical exposure, and financial integration. Rather than treating crises as homogeneous stress periods, we conceptualize them as structurally different shocks—health-driven, geopolitical, and financial-institutional—each generating distinct energy–stock interactions.

The empirical findings provide several novel insights. Crude oil (WTI) emerges as a crisis-contingent safe haven, acting as a strong diversifier in tranquil periods and offering effective downside protection during systemic shocks, particularly in Russia, India, and China. Elevated hedge ratios during crisis episodes confirm their relevance for risk reduction. In contrast, natural gas exhibits a more stable hedging profile, functioning primarily as a diversifier and hedge rather than a pure safe haven. Its relatively lower sensitivity to extreme shocks makes it particularly effective for markets such as Brazil (BVSP) and Egypt (EGX). These results demonstrate that the protective role of energy commodities is neither uniform nor static, but depends critically on both the nature of the crisis and country-specific market structures.

Collectively, these findings refine the safe-haven debate by showing that energy commodities retain practical relevance precisely because their pricing is directly linked to geopolitical tensions, supply constraints, and global trade disruptions—factors that intensify during crises. This insight goes beyond a simple extension of the country sample and underscores the importance of crisis-aware and market-specific portfolio design, especially in emerging economies where traditional financial hedges may lose effectiveness.

From a practical asset-allocation standpoint, the results imply that investors and portfolio managers should abandon static hedging strategies in favor of adaptive, crisis-sensitive reallocations. Increasing exposure to crude oil during periods of heightened uncertainty can enhance downside protection, while natural gas can serve as a stabilizing hedge across both normal and turbulent conditions.

Despite these contributions, the study is subject to limitations. The analysis is restricted to BRICS Plus markets and to a period dominated by exceptional global shocks, which may limit generalizability. Future research could extend this framework to other regional blocs (e.g., G7 or Middle Eastern economies), incorporate renewable energy and other commodity classes, or apply alternative methodologies—such as quantile-based or frequency-domain approaches—to further explore nonlinear and horizon-dependent dynamics.

Overall, by explicitly integrating crisis heterogeneity, advanced volatility–dependence modeling, and structurally diverse emerging markets, this study provides a differentiated and methodologically robust contribution to the literature on energy-based hedging, safe havens, and portfolio risk management.

Supplementary Materials: No supplementary materials are available.

Author Contributions: Conceptualization, R.B., and Y.S.M.; methodology, R.B.; software, R.B.; validation, R.B., and Y.S.M.; formal analysis, R.B., and Y.S.M.; investigation, R.B., and Y.S.M.; resources, R.B., and Y.S.M.; data curation, R.B., and Y.S.M.; writing—original draft preparation, R.B., and Y.S.M.; writing—review and editing, Y.S.M.; visualization, R.B., and Y.S.M.; supervision, R.B., and Y.S.M.; project administration, R.B., and Y.S.M. All authors have read and agreed to the published version of the manuscript." For a detailed explanation of the taxonomy, see <https://casrai.org/credit/>.

Funding: This research received no external funding.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors would like to acknowledge that there are no specific contributions to report in this section.

Conflicts of Interest: The authors declare no conflict of interest.

AI Use Statement: The authors confirm that no AI tools were used in the writing, editing, data analysis, or figure generation of this manuscript.

Appendix A

Appendix A1. Robustness Check – Alternative Copulas Across Sub-Periods

Pairs	Copula	Est. (S1)	AIC (S1)	BIC (S1)	Est. (S2)	AIC (S2)	BIC (S2)
WTI/BVSP	Gaussian	0.5210	-236.34	-230.70	0.4982	-228.11	-222.48
	Gumbel	1.5094	-242.48	-236.84	1.4621	-235.22	-229.58
	Student	0.6430	-263.05	-257.41	0.6185	-254.77	-248.93
WTI/RTSI	Gaussian	0.5995	-363.81	-358.18	0.5712	-352.66	-347.02
	Gumbel	1.6959	-424.88	-419.24	1.6487	-413.12	-407.48
	Student	0.9560	-448.23	-440.52	0.9214	-436.85	-429.14
WTI/BSE	Gaussian	0.4075	-86.92	-81.29	0.3821	-79.44	-73.81
	Gumbel	1.3483	-118.51	-112.87	1.3126	-109.63	-103.99
	Student	0.3436	-129.95	-123.37	0.3298	-121.72	-115.14
WTI/SSE	Gaussian	0.5424	-159.86	-154.23	0.5187	-148.93	-143.30
	Gumbel	1.5506	-214.33	-208.70	1.4981	-201.44	-195.80
	Student	0.4873	-228.62	-221.98	0.4639	-216.88	-210.24
WTI/JTOPI	Gaussian	0.4812	-191.77	-186.14	0.4528	-179.54	-173.91
	Gumbel	1.4263	-203.10	-197.47	1.3887	-192.73	-187.09
	Student	0.5124	-219.66	-212.98	0.4875	-207.34	-200.66
WTI/EGX30	Gaussian	0.3994	-46.59	-40.95	0.3722	-39.28	-33.64
	Gumbel	1.3469	-96.21	-90.58	1.3091	-87.44	-81.80
	Student	0.4216	-108.75	-102.07	0.3984	-99.63	-92.95
WTI/MERV	Gaussian	0.5292	-237.68	-232.05	0.5033	-225.41	-219.78
	Gumbel	1.5250	-267.93	-262.29	1.4765	-254.66	-249.02
	Student	0.5811	-283.84	-277.16	0.5528	-270.57	-263.89
WTI/TASI	Gaussian	0.4693	-131.94	-126.31	0.4446	-120.77	-115.13
	Gumbel	1.4279	-169.29	-163.65	1.3882	-157.48	-151.84
	Student	0.5037	-182.91	-176.23	0.4721	-170.88	-164.20
WTI/ADX	Gaussian	0.5318	-156.72	-151.09	0.5074	-145.39	-139.76
	Gumbel	1.4883	-184.15	-178.52	1.4437	-172.83	-167.19
	Student	0.5664	-198.47	-191.79	0.5348	-186.65	-179.97
Gas/BVSP	Gaussian	0.1577	-8.40	-2.77	0.1394	-6.21	-0.58
	Gumbel	1.1299	-22.91	-17.28	1.1086	-20.44	-14.80
	Student	0.0829	-46.51	-35.24	0.0751	-42.77	-31.50
Gas/RTSI	Gaussian	0.3098	-43.32	-37.69	0.2871	-39.54	-33.91
	Gumbel	1.2430	-67.68	-62.05	1.2145	-62.33	-56.70
	Student	0.3364	-82.91	-76.23	0.3127	-77.55	-70.87
Gas/BSE30	Gaussian	0.1324	-3.93	1.70	0.1185	-2.11	3.53
	Gumbel	1.1342	-23.71	-18.08	1.1094	-20.65	-15.02
	Student	0.1458	-35.66	-28.98	0.1312	-31.47	-24.79
Gas/SSE	Gaussian	0.3344	-19.59	-13.95	0.3098	-16.42	-10.79
	Gumbel	1.2385	-47.55	-41.91	1.2014	-42.88	-37.24
	Student	0.0188	-108.51	-97.25	0.0156	-101.73	-90.47
Gas/JTOPI	Gaussian	0.1507	-9.27	-3.63	0.1368	-7.44	-1.80
	Gumbel	1.1117	-18.53	-12.90	1.0874	-16.88	-11.24
	Student	0.1725	-29.84	-23.16	0.1583	-26.73	-20.05

Notes: “Copula” refers to the copula family specification (Gaussian, Gumbel, or Student-t). “Est.” denotes the estimated copula dependence parameter (θ). “S1” corresponds to Sub-period 1 (pre-crisis period: January 4, 2016 – December 31, 2019), while “S2” refers to Sub-period 2 (crisis period: January 1, 2020 – January 5, 2024). AIC and BIC represent the Akaike and Bayesian Information Criteria, respectively, used for model comparison. Lower values of AIC and BIC indicate a better goodness-of-fit.

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