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Geopolitical risk and extreme spillovers among oil-based energy commodities

Evžen Kočenda^a, Peter Albrecht^b, and Daniel Pastorek^b

Abstract

We investigate the impact and propagation of geopolitical risk among oil-based energy commodities. First, we endogenously identify key geopolitical events affecting the connectedness among the oil-based commodities and then evaluate their transitory and persistent impacts. We identify four major shocks that resulted in persistent shifts in connectedness: the 9/11 attacks, the Crimea crisis, the political shift in Nigeria, and the Russian invasion of Ukraine. Using a quantile-based framework, we demonstrate that volatility transmissions due to geopolitical risk are not uniform but significantly depend on market conditions. Notably, heating oil and crude oil are identified as primary transmitters of risk, especially during economic turmoil. We quantify the negative economic and financial impacts of geopolitical risks through a multivariate dynamic portfolio analysis and through an impact on the profitability of ten global banks with high exposure to oil commodities. Our findings enhance the understanding of how geopolitical shocks influence connectedness and informed portfolio decisions, highlighting the need for adaptive strategies in finance.

JEL classification: C32; C58; G15; Q02; Q35

Keywords: geopolitical risk; extreme market conditions; oil-based energy commodities; volatility connectedness; transitory and persistent effects; portfolio composition and hedging; global banks with high exposure to oil.

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1. Introduction

Geopolitical risks, including regional conflicts, trade disruptions, and policy tensions, profoundly impact energy markets, with significant implications for global economic stability and security (Aastveit et al., 2017; Tran, 2019). In particular, oil-based energy commodities are central to modern economies (Timilsina, 2015). They are linked to climate change (Lin et al., 2024), and their price fluctuations, driven by geopolitical events, have far-reaching consequences (Nandha and Faff, 2008; Mohaddes and Pesaran, 2017; Gogolin et al., 2018). Attacks, tensions, and wars have demonstrated the vulnerability of energy markets to geopolitical disturbances, raising questions about the transmission of volatility and the connectedness among these critical commodities (Malik and Hammoudeh, 2007; Nazlioglu et al., 2015; Patidar et al. 2024). Understanding the extent and nature of this connectedness during periods of geopolitical turmoil is vital for policy-makers, economists, and investors, as it shapes policy responses to stabilize markets and risk management strategies (Gorton and Rouwenhorst, 2006; Kočenda and Moravcová, 2024). Despite its importance for economic consequences, we still do not have solid evidence on several key facets. What are truly impactful geopolitical risk shocks, and what is their role in dramatic changes in connectedness among energy commodities? Is their impact temporary or persistent? How does the connectedness among energy commodities evolve during periods of extreme market conditions, especially severe distress, compared with optimistic times? How can the impact of geopolitical risk be quantified in terms of economic and financial consequences? We offer more detailed motivation for the above issues presently, and our analysis provides answers to the above questions using data-grounded empirical evidence.

Geopolitical risk impacts price dynamics in commodity markets (Karali et al., 2019) and is closely related to connectedness among oil-based energy commodities, which reflects how price shocks in one commodity propagate through others, affecting portfolios and investment decisions on a global scale (Kočenda and Moravcová, 2024). The quantification of volatility connectedness, primarily developed by Diebold and Yilmaz (2009, 2012), is grounded in variance decompositions from vector autoregression (VAR) model and measures how shocks originating in one commodity influence the price volatility of others, representing a "spillover" effect crucial to understanding systemic risk within the energy sector. More recently, a quantile-based approach, as outlined by Ando et al. (2022), allows for the differentiation of these spillovers across distinct market conditions, particularly under extreme distress triggered by geopolitical events. Such a quantile framework is essential for assessing how risk propagation

differs in stable versus volatile periods, helping decision-makers and subjects exposed to commodity price variations cope with economic impacts (Adekoya and Oliyide, 2021) and allowing investors to anticipate asset interdependence and adjust their hedging and portfolio strategies accordingly (Garcia and Tsafack, 2011; Feunou and Okou, 2019; BenMabrouk et al., 2024).

What geopolitical events impact connectedness among energy commodities, and how is this influence realized? Relevant studies on energy commodity markets conclude that increases in connectedness are tied to economic or political shocks (Chevallier and Ielpo, 2013; Yip et al., 2017; Kočenda and Moravcová, 2024). However, such conclusions are not drawn from statistically grounded testing; thus, we take a different approach. We employ a novel procedure developed by Greenwood-Nimmo et al. (2024) and endogenously detect thirteen impactful events with a statistically significant effect on connectedness among energy commodities.¹ Furthermore, most previous studies have not fully addressed the question of whether the impacts of geopolitical shocks on volatility connectedness are transitory or persistent. We aim to bridge that gap by applying a novel approach that evaluates oil-based commodities' short- and long-term responses to geopolitical risk events. Building on the framework introduced by Baruník and Ellington (2024), we provide evidence of persistent and temporary changes in connectedness linked to specific events. Specifically, we identify four critical events that can be linked to a persistent change in energy commodity connectedness. Additionally, we analyse how several key factors, such as geopolitical risk, credit risk, economic activity, and monetary policy, are linked to energy commodity connectedness under extreme market conditions. Our analysis reveals that geopolitical risk is linked with substantial increases in connectedness during periods of extreme market volatility as well as under normal conditions. Additionally, a decline in economic activity heightens connectedness during economic downturns, whereas widening credit spreads positively affect connectedness under both standard market conditions and times of severe stress. Furthermore, monetary policy exerts a substantial impact across all market regimes, although the extent of its influence varies.

In addition to understanding how geopolitical risk shapes volatility dynamics and portfolio composition, it is equally important to examine how these systemic spillovers affect the financial sector, particularly banks with high exposure to oil-based commodities. While the

¹ Kočenda and Bartušek (2025) applied the procedure of Greenwood-Nimmo et al. (2024) with a broad scope of several types of events. They showed that economic and natural events are less impactful than geopolitical events. We concentrate chiefly on events associated with geopolitical risks that produce the most pronounced effects on connectedness among energy commodities and that subsequently result in the most critical economic and financial outcomes.

literature has extensively explored the macroeconomic and asset-pricing consequences of oil price shocks, the role of commodity connectedness as a transmission channel to bank profitability remains underexplored. This is a critical omission, given that banks not only absorb shocks but also propagate them through credit, liquidity, and capital channels. In this paper, we address this gap by quantifying how time-varying connectedness, driven by geopolitical risk, affects the profitability of globally active banks. By linking commodity market interdependencies with bank-level outcomes, we provide a novel perspective on how systemic risk originating in energy markets can influence financial stability. This approach complements our portfolio analysis and extends the relevance of connectedness beyond investment strategies to macro-financial resilience.

In the final part of our analysis, we evaluate the impacts of geopolitical risk in economic and financial terms. We begin with the theoretical foundation for multi-asset portfolio analysis rooted in the portfolio theory developed by Markowitz (1959), which emphasizes diversification to reduce risk. We extend this theory to the context of geopolitical risk by applying portfolio optimization techniques to a connectedness-based framework. By constructing portfolios with minimal connectedness among energy commodities, on the basis of the pairwise connectedness indices proposed by Broadstock et al. (2022), our analysis explores how geopolitical shocks lead to structural adjustments in portfolio composition. Such adjustments are essential for reducing exposure to systemic risk and enhancing resilience in the face of unexpected volatility. Moreover, this approach reflects the interconnectedness of global energy markets, where disruptions in one region rapidly propagate through various commodities, underscoring the importance of adaptive strategies in portfolio management. In the second step, we evaluate how geopolitical risk via connectedness affects banks with substantial exposure to oil-based commodities. Oil price fluctuations have been shown to exhibit profound implications not only for macroeconomic activities (Hamilton, 1983, 1996) but also to impact bank performance (Hesse and Poghosyan, 2016; Çikiryel et al., 2024). Multinational banks with high exposure to oil commodities are associated with heightened instability in lending activities, as extreme global events and systemic shocks affecting the oil market can rapidly alter foreign banks' lending patterns. These impacts ultimately materialize in bank performance, and banks must actively account for the volatility of these markets and their spillovers, captured by connectedness, by adopting robust hedging strategies to protect their profitability. Hence, while oil price fluctuations are one of the drivers of bank performance, the interconnectedness among oil-based commodities provides an additional layer of systemic risk transmission that can amplify the impact on profitability of banks. Monitoring these

linkages is therefore essential for understanding the broader implications of commodity market dynamics on bank performance. For that, we explore how geopolitical risk propagating via time-varying connectedness impacts the profitability of ten banks highly exposed to oil-based commodities. We show that connectedness negatively impacts bank profitability during both periods of extreme distress as well as positive market sentiment. Similarly, adverse factors such as interest rates and non-performing loans exhibit the highest impact on bank profitability during both extremes rather than during standard market conditions. These findings underscore the importance of managing financial and operational risks tailored to different market scenarios, which is in line with the findings of previous multivariate portfolio analyses.

In summary, we present novel evidence on issues not yet explored in the literature. First, on the basis of a novel procedure, we endogenously define major geopolitical risk events affecting the dynamics of connectedness among energy commodities. Then, we identify and distinguish between the transitory and persistent impacts of shocks on volatility transmissions for energy commodities, identifying four shocks that led to a persistent shift in connectedness. Furthermore, we examine connectedness across quantiles, differentiating between the propagation of volatility during periods of extreme distress, standard market conditions, and positive sentiment. Our findings indicate that heating oil and crude oil are the primary transmitters of volatility, particularly during geopolitical turmoil. Furthermore, we show the role of geopolitical risk and uncertainty, economic activity, credit risk, and monetary policy in the dynamics of volatility propagation. Finally, we quantify the impacts of geopolitical risk in economic and financial terms by showing the dynamics of multivariate portfolios across periods defined by the four critical persistent shocks. We also demonstrate the negative impact of heightened connectedness on the profitability of banks with high exposure to oil commodities.

The rest of the paper is organized as follows: Section 2 presents the study's theoretical background. Section 3 explains the data, and in Section 4, we present the methods used in our analysis. Section 5 empirically examines the connectedness among oil-based energy commodities, and Section 6 concludes.

2. Literature review

Geopolitical uncertainties and global pandemic events have always affected the trend of crude oil prices, and Patidar et al. (2024) proposed a big-picture link between significant changes in the price of crude oil and global events. Individual contributions to a field illustrate more nuanced facets of geopolitical risk propagation.

During elevated political uncertainty, established commodity price patterns may be disrupted (Albrecht et al., 2025). Surprising political shifts reduce the importance of traditional variables in determining the value of commodities (Abaidoo and Agyapong, 2022). Abnormal swings become more pronounced due to heightened risk aversion throughout the economy (Tran, 2019), which affects the accuracy of models that rely on standard economic factors (King, 1994), including shifts in investor behaviour (Pastor and Veronesi, 2012). Investors are inclined to dispose of assets with increased riskiness (Tran, 2019). Additionally, geopolitical uncertainties lead to a downturn in bank profitability as well as business activity, negatively affecting commodity prices. Political-based turmoil contributes to increased asset volatility (Carnahan and Saiegh, 2021), which spreads to other countries (Adrian and Brunnermeier, 2016). Recently, Kočenda and Bartušek (2025) brought new insights into the dynamics of oil-based energy commodities by providing the first evidence about the association of shocks and spikes in connectedness values. The authors examined four oil-based commodities over a period of forty years and identified several important events that affected volatility connectedness for up to one business month ahead. Moreover, the authors confirmed that geopolitical events had the greatest effect on propagation effects among other types of shocks, such as economic and natural shocks. However, they did not account for extremes or events after 2022; nor did they distinguish between transitory and persistent impacts of events. Furthermore, Abaidoo and Agyapong (2022) investigated the relationship between commodity price volatility and political stability in emerging economies. Their findings confirmed the relationship between volatility in the prices of commodities (crude oil, copper, and coal) and political (in)stability, highlighting the interconnectedness between commodity markets and political environments. However, the authors did not account for the transmission of these shocks.

The study of quantile connectedness (as explored by Adekoya and Oliyide, 2021; Chowdhury et al., 2021; and Ando et al., 2022) offers a more nuanced perspective on how the relationship between variables varies across different segments of their distributions. Notably, during shocks with political backgrounds, connectedness tends to exhibit extreme values (Yousfi and Bouzgarrou, 2024). Further, in a multi-commodity analysis, Albrecht et al. (2025) show that oil receives up to 90% of spillovers from other commodities (coal, metals), and the proportion is highest during periods of distress. In sum, quantile connectedness analysis provides valuable insights into the interplay between variables across different market regimes, particularly under critical conditions, by uncovering hidden dependencies that enhance both portfolio construction and systemic risk management. Nonetheless, so far, the literature has devoted comparatively less attention to how these tail-driven propagation patterns interact with

broader macroeconomic fundamentals, such as economic activity or interest rate dynamics, and their potential implications for bank sector performance.

The gap is especially salient given the dual role banks play as key facilitators of financial intermediation and as stabilizers of macroeconomic systems. During periods of extreme market conditions (distress or exuberance), the connectedness structure among commodity markets undergoes profound shifts that can either magnify or obscure underlying risk exposures. These shifts directly affect banks with significant commodity-linked portfolios by reducing diversification benefits and increasing vulnerability to concentrated losses. At the same time, the connectedness shifts intersect with macroeconomic fundamentals that influence the overall resilience of the financial system. Understanding these interconnections is therefore crucial for assessing how tail risk in commodity markets transmits to bank profitability and interacts with the broader economic environment. In negative tail scenarios, heightened synchronization among commodities undermines diversification benefits, exposing banks with commodity-linked portfolios to concentrated losses (Claessens and van Horen, 2014). Conversely, in positive tail regimes, excessively low connectedness implies idiosyncratic behavior among commodities, complicating the prediction of co-movements and reducing the effectiveness of hedging strategies (Hou and Pan, 2022). These dynamics increase model risk and challenge the robustness of risk management frameworks. Given that banks are both recipients and transmitters of systemic shocks, understanding how tail-connectedness affects their profitability is crucial for assessing financial sector resilience. This perspective aligns with recent calls in the literature (e.g., Balli, 2023) to explore how sectoral vulnerabilities interact with market interdependencies. By linking tail risk in commodity markets to bank-level outcomes, we contribute to a more comprehensive understanding of how geopolitical and financial shocks propagate through the economy, with implications for both investors and regulators. By employing quantile connectedness analysis, researchers can precisely examine these exceptional cases, leading to a deeper understanding of the dynamics and transmissions associated with tail risk and extreme events.

Finally, frequency connectedness analysis becomes essential for investigating the structure and dynamics of connectedness between commodities and commodity currencies during geopolitical shocks (e.g., Baruník and Kočenda in 2019; Baruník and Ellington in 2024). Persistency connectedness analysis reveals the impact of such shocks on assets, considering both transitory (short-term frequency response) and persistent effects (long-term frequency response). These effects create frequency-dependent linkages within the system. For example, Corsi and Renò (2012) reported that stressful events in daily or weekly data tend to have

transitory impacts. However, if a shock persists and affects financial markets for more than one business month, it tends to modify the system more persistently.

3. Data

3.1. *Commodity prices data*

We quantify the connectedness among four energy commodities: crude oil, heating oil, gasoline, and diesel. These commodities are closely linked because approximately 60% of global crude oil stock is used in producing heating oil, diesel, and gasoline. Additionally, heating oil can be a byproduct of processing crude oil into gasoline. Furthermore, heating oil often acts as a substitute in various economic processes (Liu and Tang, 2013).

We obtained our data from Refinitiv Eikon Datastream, from where we downloaded next month's futures contracts from two exchanges: West Texas Intermediate Crude Oil, RBOB gasoline, NY Harbor Ultra Low Sulphur Heating Oil, and Low Sulphur Diesel (from the Intercontinental Exchange in Europe). Eikon Datastream provided daily open, close, high, and low prices for all five commodities. For gasoline, we derived range-based data from high-frequency intraday prices using TickData.² Specifically, we calculated range-based realized volatility (RV) estimates based on the method introduced by Garman and Klass (1980), as described in Section 5. Our data covered the period from September 1, 1978, to March 28, 2024, for all oil-based commodities. Consequently, we conducted two separate analyses: one focusing solely on petroleum-based commodities and another including all four commodities starting from April 3, 1990.

We encountered anomalies in the price data, including weekends and holidays. On weekends, prices were sometimes reported, but we removed those instances. We also excluded Christmas and New Year's holidays (December 24 - December 26, December 31, and January 1 - 2) and US Federal holidays when the exchange in our dataset was closed. Additionally, we identified 486 days where the low (high) price deviated unexpectedly from the remaining range-based prices for at least one commodity. In such cases, we substituted the low (high) value with another range-based value. Overall, there were 161 days with missing data for at least one commodity. To address this, we input the missing values using a 5-day rolling average of realized volatility (RV). Ultimately, we had 9135 days of RV values for petroleum-based commodities.

² <https://www.tickdata.com/product/historical-futures-data/>

For estimating the effect of several factors on connectedness during extreme versus normal market conditions represented by relevant quantiles (0.05, 0.50, and 0.95), we employed the following determinants: geopolitical risk, credit risk, economic and monetary conditions. The Geopolitical Risk (GPR) Index is used as a proxy for market uncertainty related to geopolitical events, trade policies, and governmental actions. It is a measure developed by Caldara and Iacoviello (2022), focusing specifically on the frequency and intensity of geopolitical threats, such as diplomatic tensions, military threats, and other non-violent forms of international friction. The index quantifies geopolitical risk by analysing news-based mentions of geopolitical tension, including references to military threats, diplomatic disputes, and acts of terrorism. The data for the geopolitical risk index were obtained from Matteo Iacoviello's official website.³

We quantify credit risk using an independent metric suggested by Menkhoff et al. (2012). The credit risk is measured via credit spread, defined as the difference between the 90-day AA Financial Commercial Paper rate (CPF3M) and the 3-month Treasury bill rate (TB3MS); both rates are widely used to define a market spread and reflect funding costs. We further examine the impact of monetary conditions that are represented by the US 5-year Treasury yield (Della Corte et al., 2022). We use the 5-year U.S. Treasury yield as a benchmark for medium-term, risk-free interest rates.⁴ Finally, we employ the S&P 500 index as a proxy for economic activity, as outlined by Davis et al. (2022). Monthly frequency data for credit spreads, treasury yield, and the S&P 500 Index were sourced from the Federal Reserve Economic Data (FRED) database at a monthly frequency from January 2005 to March 2024. The period was chosen to capture market dynamics across multiple economic regimes, including pre-crisis stability, financial crisis, post-crisis recovery, and recent periods of increased geopolitical and economic uncertainty. We present the summary statistics of the above determinants (geopolitical risk, credit risk, economic and monetary conditions) in Appendix Table A8. We also present the correlations among the variables in Appendix Table A9 and show that all correlations are well below the standard threshold, which justifies their inclusion in the estimated specification.

³ <https://www.matteoiacoviello.com/gpr.htm>

⁴ Despite the Federal Funds Rate could be used as a measure of monetary policy stance, we opt for using the 5-year U.S. Treasury yield, as previous studies (e.g., Menkhoff et al., 2012; Della Corte et al., 2022; Albrecht and Kočenda, 2025) have shown it to be a more informative proxy in the context of our analysis. The reason and advantage of using the 5-year U.S. Treasury yield lies in its ability to capture not only the current level and changes in short-term interest rates but also market expectations about future monetary policy adjustments. As such, it serves as a more forward-looking indicator of a monetary policy stance. It also has greater potential to act as a leading signal of policy shifts, particularly in the context of financial market responses to anticipated interest rate trajectories.

Further, we quantify the effect of the geopolitical risk propagating via time-varying connectedness at different market conditions (measured at quantiles) on the profitability of ten globally active banks that are highly exposed to oil-based commodities. These banks are JP Morgan Chase & Co., Bank of America Corporation, Wells Fargo & Company, Citigroup Inc., Morgan Stanley, BNP Paribas, Goldman Sachs Group Inc., Barclays Plc., Deutsche Bank AG., and Mizuho Financial Group (Ambrose, 2024; Statista, 2024). We downloaded the data for each bank to quantify their profitability measured as return on average equity (ROAE). We also downloaded bank-specific indicators measuring equity, total assets, Tier 1 capital ratio (ratio of core equity capital to its total risk-weighted assets), and non-performing loans (NPL). The yearly data were downloaded from the ORBIS database and range from 1998 to the most recent values in 2023. From a Bloomberg Terminal, we further downloaded data to account for the macroeconomic conditions: global GDP growth, global CPI, USD real effective exchange rate (REER), U.S. 3-month interest rate, and a global economic-policy uncertainty (EPU) index as a proxy for global uncertainty.

We present the summary statistics of the above bank-specific characteristics and macroeconomic conditions in Appendix Table A8. We also present the correlations among the variables in Appendix Table A10 and show that all correlations are well below the standard threshold, which justifies their inclusion in the estimated specification. The variables were tested for unit-root, and first-differencing was used as a transformation to achieve their stationarity where needed. All variables used for estimation are stationary (Appendix Table A11).

3.2. Geopolitical oil-related events: Definitions and search

Our dataset comprises 391 geopolitical oil-related events spanning from January 1, 1987, to March 28, 2024. These events represent geopolitical shocks that we divided into six main categories: missile, political, peace, war, threat, and strike. To account for weekends and holidays (when price data is unavailable), we shifted any event occurring on Saturday or Sunday to the following Monday (a working day). The approach ensures an effective pairing of events with the first market reaction date.

We curated information from various sources, including prominent news organizations, international bodies, and academic literature. For academic sources, we conducted a Google Scholar search using a common query related to oil ('oil' OR 'petrol' OR 'petroleum' OR 'tanker') AND ('history' OR 'historical' OR 'event' OR 'news' OR 'policy' OR 'headline' OR 'announcement' OR 'chronology' OR 'case study').

Initially, we used a common query for all events. In the next step, we tailored specific queries for each type of event. We incorporated additional terms related to geopolitics, wars, elections, and crises: AND ('geopolitical' OR 'geopolitics' OR 'war' OR 'peace' OR 'conflict' OR 'battle' OR 'election' OR 'collapse' OR 'coup' OR 'crisis' OR 'intervention'). Our queries yielded approximately 3,870,000, 4,180,000, and 3,560,000 hits, respectively. For each query, we analyzed the first 200 results. These chosen sources provided valuable references for a multitude of oil-related events.

We reached out to international organizations such as the United Nations, Human Rights Watch, the Federal Trade Commission, OPEC, and NATO. Additionally, we selected news organizations including Reuters, Bloomberg, NY Times, LA Times, Economic Times, Washington Post, BBC News, CBS News, CNN, The Wall Street Journal, Yahoo, Cato Institute, The Guardian, and MarketWatch. Our search focused on articles containing keywords like 'oil,' 'petroleum,' and 'petrol,' published between 1987 and 2024. To avoid duplication, we cross-checked news events from these sources. The final selection yielded 391 geopolitical events. Geopolitical events covered war conflicts, terrorist attacks, missile launches, bombings, governmental elections, civil wars, political statements, meetings of leaders, peace agreements, and strikes. Most of the gathered events are associated with or originate in oil-exporting countries, but our event search did not impose any restrictions on the origin of the news.

4. Methods

4.1. Connectedness

Diebold and Yilmaz (2009, 2012) quantified the connectedness index based on vector autoregressions (VAR) and rooted in variance decomposition. The approach allows for assessing different proportions of variance in the H -step forecast errors, considering both shocks and interconnected variables. Specifically, the technique links the variance decomposition matrix to a vector autoregression model with N variables. Connectedness, in this context, represents the proportion of H -step forecast errors associated with the forecast of variable x_i , given shocks in variable x_j (where $i, j = 1, 2, \dots, N$). The contribution of the j component to the forecast error in the i component can be defined as follows:

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

At time t , we denote A_h as the coefficient for the moving average forecast. It is crucial to observe that the cumulative variances in each row may not necessarily sum to I , since

$\sum_{j=1}^N \theta_{ij}^g(H) \neq 1$. The standard deviation of the error component is represented by σ_{jj} , and both e_j and e_i serve as selection vectors. The total connectedness index, as elucidated by Diebold and Yilmaz (2012), captures the impact of shocks on the collective forecast error variance within the variable set.

$$S^H = \frac{\sum_{j=1, j \neq i}^N S_{i \leftarrow j}^H}{\sum_{i,j=1}^N S_{i \leftarrow j}^H} = \frac{\sum_{i,j=1, i \neq j}^N S_{i \leftarrow j}^H}{N}. \quad (2)$$

To analyze the interconnectedness dynamics, we employ a rolling window spanning 100 days from $t-99$ to t . For normalizing volatility spillover and accounting for variable shocks, we utilize total forecast error variance decompositions. The cumulative H -step spillovers for each matrix row remain fixed at 1 ($\sum_{j=1}^N S_{i \leftarrow j}^H = 1$), while the overall spillovers across all variables sum to N ($\sum_{i,j=1}^N S_{i \leftarrow j}^H = N$). In line with prior research (Diebold and Yilmaz, 2012), we select a VAR lag length of 2 and a forecast horizon of $H=10$.

4.2. Endogenous detection of geopolitical risk events

We endogenously detect major events of geopolitical risk that exhibit statistically significant links with subsequent increases of connectedness. The procedure was designed by Greenwood-Nimmo et al. (2024) and in the following account we adhere closely to the original notation. We begin with calculating the Diebold and Yilmaz connectedness metric as outlined in the specification (2) and proceed with two phases of bootstrapping. The initial phase produces bias-adjusted bootstrap estimates. We outline the steps of the method applied to an orthogonalized connectedness index (which is influenced by variable ordering) as follows: (i) estimate and record the residuals \hat{u}_t , the (orthogonalized) connectedness index values S^{Ho} and the parameter estimates \hat{A}_j ; (ii) extract B bootstrap samples from x_t : $x_t^{(b)} = \sum_{j=1}^p \hat{A}_j x_{t-j}^{(b)} + u_t^{(b)}$.

The VAR residuals are utilized to compute $u_t^{(b)}$, with p serving as the initial value. (iii) Subsequently, B bootstrap samples are generated and employed to re-estimate the VAR model. It yields new estimates for the residuals, connectedness index, and parameters. (iv) The formula used to determine the bias between the bootstrap measurements is $\hat{Y}_o = B^{-1} \sum_{b=1}^B S_{Ho}^{(b)} - S_{Ho}$. (v) The entire procedure from steps (ii) to (iv) is then repeated to obtain new B estimates through bootstrapping, with the bias \hat{Y}_o subtracted each time. Finally, (vi) all steps (i)-(v) are reiterated for each observation in the rolling sample to provide statistical data for all observations.

We apply the previously described method to determine the likelihood of a statistically significant link between a specific geopolitical event (day) and a particular value (spike) of the

connectedness measure. Specifically, we continuously calculate the probabilities outlined in equation (3) as the rolling samples progress:

$$Prob\left(100 \times \left[\frac{S_{t+i} - \bar{S}_{t-j}}{\bar{S}_{t-j}}\right] > \alpha\right), i \in \{0, 1, \dots\}, j \in \{1, 2, \dots\}, \quad (3)$$

In our study, we determine the spillover index, denoted as S_{t+i} , by utilizing bootstrapping methods on a rolling sample that ends on day $t+i$. As a benchmark, \bar{S}_{t-j} represents the average spillover index across multiple bootstrap samples within the specified rolling window.

To identify the length of the impact of significant events with notable changes in the spillover index, we proceed as follows. First, set $j = 1$ and consider $i \in \{0, 1, 5, 10, 22\}$. Next, define α as 5%, indicating the degree of variation in the connectedness index. Whenever the probability at time $t+i$ (where $i = 0$) meets or exceeds 90%, we mark the day t as a statistically significant event. Such events result in a change of 5% or more in the connectedness index. By specifying $i \in \{0, 1, 5, 10, 22\}$, we can make statistical inferences about the impact of shocks on connectedness occurring 1, 5, 10, and 22 days after the event.

4.3. Transitory and persistent impacts on connectedness

Baruník and Ellington (2024) propose an economic model that captures both persistent and transitory changes in connectedness. Specifically, they advocate for a time-varying parameter vector autoregressive (TVP-VAR) model with heteroskedasticity. In this framework, the economy is represented as $X_{t,T} = \Phi_1(t/T)X_{t-1,T} + \dots + \Phi_p\left(\frac{t}{T}\right)X_{t-p,T} + \varepsilon_{t,T}$. Here, $X_{t,T}$ denotes the economic variables at time t with a lag of T , $\Phi_i(i/T)$ are the time-varying coefficients, and $\varepsilon_{t,T}$ represents the error term. To estimate the TVP-VAR, we follow Petrova (2019) who uses the quasi-Bayesian local likelihood (QBLL) technique. The method allows us to obtain time-varying coefficients and covariance matrices at a specific time point $u = t_0/T$, denoted as $\hat{\Phi}_1(u), \dots, \hat{\Phi}_p(u)$ and $\hat{\Sigma}(u)$. The QBLL approach emphasizes observations close to the period of interest, enhancing the precision of the estimates. Baruník and Ellington (2024) further utilize a Normal kernel with a weight of ($W = 8$) for their analysis, which we follow. By adopting a Bayesian estimation approach, they construct network measures with confidence intervals based on the parameter distribution. Importantly, the use of conjugate priors ensures an analytical posterior distribution of the model parameters. Consequently, Markov chain Monte Carlo simulations are unnecessary, and parallel computing becomes feasible.

In our analysis, we employ a finite horizon denoted as H to estimate the dynamic adjacency matrix ($\hat{\theta}$). The primary purpose of this approach is to mitigate the infinite vector moving average $\text{VMA}(\infty)$ representation inherent in the approximating model. Notably, the horizon H pertains to the frequency domain and does not carry significance in the time domain. Drawing inspiration from Baruník and Ellington (2024), we adopt a truncation horizon of 100 for our empirical study. Specifically, we focus on estimating the j,k element of the dynamic adjacency matrix. To achieve this, we examine the horizon $d = (a, b)$, where both a and b fall within the range of $(-\pi, \pi)$, with $a < b$, and consider the time point $u = t_0/T$. The resulting dynamic adjacency matrix is formally defined as follows:

$$[\hat{\theta}(u, d)]_{j,k} = \frac{\hat{\sigma}_{kk}^{-1} \sum_{\omega \in d} ([\hat{\Psi}(u, \omega) \hat{\Sigma}(u)]_{j,k})^2}{\sum_{\omega \in (-\pi, \pi)} [\hat{\Psi}(u, \omega) \hat{\Sigma}(u) \hat{\Psi}^T(u, \omega)]_{j,k}} \quad (4)$$

To estimate the impulse transfer function $\hat{\Psi}(u, \omega)$, we employ the inverse Fourier transform applied to a finite set of impulse response functions over a specific horizon. Specifically, we compute $\hat{\Psi}(u, \omega)$ as a weighted sum of $\hat{\Psi}(u, h)$ $W h \in \{0, 1, \dots, H-1\}$, where H represents the chosen truncation horizon following Baruník and Ellington (2024). The resulting frequency range, denoted by $\omega \in \{aH/2\pi, \dots, bH/2\pi\}$, holds significance in terms of the time scale of interest. Specifically, for daily data, we interpret the transitory (short-term) network as corresponding to horizons of 1 to 5 days, while the persistent (long-term) network aligns with horizons exceeding 20 days. To achieve this, we set the frequency band as $(a, b) = (2\pi/5, 2\pi)$ for the transitory network and $(a, b) = (0, 2\pi/5)$ for the persistent network. By estimating Equation (2) and its modified versions related to directional spillovers, we directly derive estimates for the dynamic adjacency matrix defined in Equation (5) across the specified time scales, consistent with the approach of Baruník and Ellington (2024).

4.4. *Multivariate portfolios*

To demonstrate the impact of geopolitical risk shocks in financial terms, we analyze those impacts on investment portfolios composed of oil-based commodities. The analysis assumes that the investor has direct access to these commodities and focuses solely on energy-based oil commodities. Although these are relatively specific assumptions, they adequately serve our illustrative purposes. We explore various connectedness-based portfolios. Please note that only concise descriptions of the selected strategies are provided.

Following Broadstock et al. (2022), we create a minimum connectedness portfolio in the context of the minimum variance portfolio of Markowitz (1959) and the minimum correlation portfolio by Christoffersen et al. (2014), where the portfolio weights (w) use the conditional correlation matrix instead of the conditional covariance matrix. We construct a portfolio with minimal connectedness (*MCoP*) by using all pairwise connectedness indices (*PCI*) instead of the variance or correlation matrix. By reducing the level of connectedness among variables, and thus their spillover effects, we achieve a portfolio that is less susceptible to and more resistant against network disruptions. Consequently, investment instruments that neither exert influence on others nor are influenced by them will receive greater weight in the portfolio. The concept can be articulated as follows:

$$\omega_{Rt} = \frac{PCI_t^{-1}I}{I PCI_t^{-1}I}. \quad (5)$$

Here, PCI_t represents the matrix of pairwise connectedness indices, while I denotes the identity matrix (Broadstock et al., 2022).

5. Results

5.1. Connectedness at extreme and regular market conditions: Quantiles and their dynamics

In our initial analysis, we assess the connectedness associated with extreme values that may arise during geopolitical distress. These shocks are triggered primarily by adverse news events (at the 0.05 quantile, as indicated in Table 1) or positive news (at the 0.95 quantile, as shown in Table 3). Additionally, we compute an average connectedness measure (at the 0.50 quantile; see Table 2) that closely resembles the standard total connectedness. Our findings, based on a static sample using a quantile VAR, reveal that a significantly higher proportion of the volatility of individual commodities is from their own historical values during normal market conditions (as reflected in Table 2). However, during intense periods characterized by extreme positive and negative events, transmission effects become more pronounced (Tables 1 and 3). These results align with previous research by Munro (2004) and Atkin et al. (2021).

Tables 1 to 3 present the computations for the static sample, which explains the connectedness and transmissions among the selected commodities throughout the entire period. The first observation, which is different from other asset classes (Albrecht and Kočenda, 2024), is that a quite low percentage of the volatility of these commodities is due to their own past values. For example, oil accounts for 40–55% of volatility from past values across all quantiles (Tables 1–3). These results indicate strong connectedness among commodities, as all the

commodities receive only 20–50% volatility from their past values. Moreover, two commodities (oil and heating oil) are “net” volatility transmitters, whereas the other two (gasoline and diesel) are “net” volatility receivers (Tables 1 to 3). We confirm the robustness of the results, as they are valid for all three connectedness regimes. On a static sample, these “net” transmissions amount to approximately 5%.

Moreover, since the results are very robust among all three quantiles representing standard market conditions (0.50 quantile), positive market sentiment (0.95 quantile), and extreme distress (0.05 quantile), we study more details regarding directional spillovers. During all periods, oil is the main transmitter of volatility to heating oil (approximately 20%) and gasoline (approximately 15%). Additionally, heating oil as a net transmitter transmits volatility mainly to gasoline (approximately 10%) and then to oil (approximately 20%). Diesel is volatile from both oil and heating oil but to a lesser extent (Tables 1 to 3).

We can then obtain more details from the dynamic samples (Figure 1). We account for changes in the context of positive sentiment (0.95 quantile), standard market conditions (0.50 quantile), and extreme distress (0.05 quantile). However, the results differ to only a small extent. When quantiles represent a positive market environment, the connectedness values among these commodities were stable, sharing 50–75% of volatility spillovers. However, dynamic samples confirm our previous findings about similar transmissions among all three market regimes. This is crucial, as the implications for volatility transmitters are valid both during periods of market uncertainty and market optimism. These conclusions differ for other assets (see Ando et al., 2022). The quantile accounting for market distress is more volatile and more correlated with standard market movements (Figure 1). The propagation of volatility spillovers ranges from 25% to 75% among these commodities. Therefore, changes in connectedness occur, especially in times of geopolitical turmoil. This finding agrees with previous quantile studies (e.g., Chowdhury et al., 2021; Ando et al., 2022). However, it has not been previously identified for these commodities.

5.2. Events with transitory impacts on connectedness

In this section, we employ the procedure of Greenwood-Nimmo et al. (2024) to calculate the probability of association between an event and the rise in the connectedness measure. Table 4 presents thirteen out of 391 events found through our text mining criteria that exhibit a statistically significant impact on connectedness. Table 4 underscores the significant influence of geopolitical risk on connectedness. Our study identified thirteen geopolitical incidents that met the criteria for exerting measurable transitory influence over a four-day period following

their onset.⁵ We can see (Figure 2) that these events accounted for changes in the connectedness values for up to 60% of the volatility propagated through the sample.

The first event with a significant impact occurred on May 16, 1988, when Iraq bombed Iran's tankers. Table 4 shows that it affected the propagation of volatility for the entire business week with 100% probability. Figure 2 sheds additional light on the event, indicating that the connectedness spikes by 10% to 40% of shared volatility. We classify this event as a "missile" type.

Another four events with transitory impacts had a purely political background. These events cover the period from 1990 to 2000 and provide more detail on what fundamentals drove the oil market during those years. The first is the Geneva Peace Conference, which caused a spike in connectedness values of 30%, with its peak at almost 50% (Figure 2). The event had an instant impact on the following business week, as the countries involved failed to negotiate a resolution to the Iraqi invasion of Kuwait (Freedman and Karsh, 1993). Another political event was an unsuccessful political coup in the former Soviet Union on August 19, 1991. The event affected connectedness with 100% probability during the day and for the following four days (as documented in Table 4). We document another military coup against the government in Venezuela, which occurred on November 27, 1992; however, the event was short-lived (Norden, 1998). Another political event occurred on May 20, 1996, when the United Nations issued a memorandum of understanding with the Government of Iraq concerning the Oil-for-Food Program. The initiative initially permitted Iraq to export crude oil, generating revenues of one million U.S. dollars. These funds were strictly allocated to meet the humanitarian needs of Iraqi citizens. However, subsequent investigations revealed that the program was marred by significant corruption (Hsieh and Moretti, 2006).

During the first decade of the twenty-first century, four events affected connectedness on a transitory basis. These events had different backgrounds. The first (October 12, 2000) was attributed to a terrorist missile attack on an American warship in the Yemeni port of Aden. The event led to a sharp increase in oil prices, followed by surges in the prices of three other oil-based commodities (Table 4). The failure of the United Nations and Iraq to come to an agreement on November 27, 2002, increased the connection between the two countries for the next four days. Another shock occurred on March 20, 2003, when the U.S.-led coalition started a ground invasion of Iraq. This caused a spike in connectedness for the next four days with almost 100% probability (Table 4). Later that year (August 19, 2003), an attack on the UN

⁵ The initial day and the following four days represent one business week, defined by Corsi and Renò (2012) or Baruník and Ellington (2024) as a transitory impact.

headquarters in Iraq increased connectedness for the rest of the business week (Table 4) from 40% to 50% (Figure 2).

In the following years, the connectedness was not affected by any event until February 23, 2011, when the Arab Spring shut down half of Libyan oil production (Baumeister and Kilian, 2016). The event caused an increase in connectedness of 15% (Figure 2) and transmitted volatility to three oil-based commodities for the next four days. In the series of events that occurred during the Arab Spring in Egypt, Syria, and Libya (Table 4), this event was the only one to cause an increase in connectedness. Another event was classified as a threat; on April 1, 2013, North Korea announced that it was entering a war against South Korea. Although this event ended up being only a threat (i.e., a war did not break out), the event significantly affected connectedness during the whole business week.

On June 23, 2014, Iraqi officials publicly announced that the Baiji refinery had fallen under the control of ISIS (CNN, 2014). While it is difficult to pinpoint the specific event responsible for the observed rise in connectedness, the capture of the Baiji refinery undoubtedly played a significant role. As a result of the capture of the Baiji refinery, the propagation of volatility peaked above 50% (Figure 2) for the following four days (Table 4). The last significant transitory event we documented had a political background. On September 27, 2023, the media released a message about the planned fusion of the largest Russian oil-producing companies by the state. If true, it would have led to the creation of the second-largest oil producer worldwide. However, in the traditional spirit of Russian news releases, the messages were later denounced (CNN, 2023). Despite the event shifting the connectedness of oil-based commodities by 5%, the propagation remained at low levels (Figure 2).

From these transitory events, we can gain additional perspectives. Baruník et al. (2015) studied asymmetries in the propagation of volatility of commodities and noted that many of these transmissions are affected by shocks in the oil supply. Our results also show that most of these events were associated with oil-production disruptions or the possibility of an oil shortage. However, while the findings of Baruník et al. (2015) were based on visual inspection of the connectedness plots, our empirical evidence is based on solid statistics.

Additionally, a detailed classification of the significant events confirms that the majority were political in nature, including coups, policy announcements, and international negotiations. The prevalence of politically driven shocks suggests that oil market connectedness is not only sensitive to physical supply disruptions but also to the anticipation of regulatory and institutional changes. Such findings imply that geopolitical risk assessment frameworks should expand their scope beyond traditional conflict indicators to include signals of political

instability, electoral transitions, and diplomatic interventions. Geopolitical risk has profound implications for market participants and policymakers, as it highlights the need for predictive monitoring of political developments in key oil-exporting regions to manage volatility exposure and systemic risk propagation.

5.3. Events with persistent effects on connectedness

Baruník and Ellington (2024) recently noted that distinguishing between transitory and persistent impacts on connectedness is necessary, as persistent shifts represent systematic risk. In line with the literature, we define a persistent impact as an effect on markets that lasts longer than one business month, as such events tend to have a more ongoing influence on the system (Corsi and Renò, 2012; Baruník and Ellington, 2024; Katsoulis et al., 2024). Such an identification has not been provided for commodities in general or in the specific context of geopolitical risk events.

In Figure 2, we present the dynamics of connectedness when transitory and persistent impacts are accounted for. First, we observe that most of the changes could be attributed to temporary shocks when connectedness ranges from 15% to almost 60%. More importantly, we document the impact of four systemic shocks of a geopolitical nature. These shocks are identified in Figure 2, and the specific sources of the events and their dates are summarized in Table 5. The results confirm changes in the persistent impacts of shocks: four shocks persistently shifted connectedness by at least 5%, three of which represented geopolitical risk.⁶

The first shock is linked to the terrorist attacks in New York on 9/11. As trading was suspended immediately after the attacks, the shock materialized a week later, on September 17, 2001, the first day the markets reopened following the terrorist attacks. The impact of the attack on financial variables has been demonstrated in previous studies (e.g., Diebold and Yilmaz, 2012; Baker et al., 2016); however, they did not account for persistent changes in connectedness. This is crucial, as we are the first to confirm that this shock represented systematic risk propagation among the four examined commodities.

Another event that shifted the connectedness curve by more than 5% (Figure 2) could be attributed to the autonomy announcement in occupied Crimea on March 11, 2014. This was the peak of Ukraine–Russia tensions in 2014, which affected other financial variables, such as

⁶ We exclude the role of the COVID-19 shock because it was thoroughly investigated by Kočenda and Moravcová (2024) and because it was not a purely geopolitical shock.

currency rates (Albrecht and Kočenda, 2024). However, this is the first evidence of persistent changes in volatility propagation among energy-based commodities.

On May 29, 2015, volatility spillovers from oil transmitted to other commodities and impacted their connectedness when Nigeria, which is oil-rich and an important oil supplier, inaugurated a new president. The event represented the first-ever democratic shift between political parties; on that day, protests occurred due to accusations of rigged elections (Payne, 2015). The distress linked to protests that might impact oil availability led to a persistent shift in volatility propagation by 5%.

The final geopolitical shock with a persistent effect on the volatility propagation of oil-based energy commodities was the Russian invasion of Ukraine on February 24, 2022, whose multifaceted impact has been documented in recent literature (Zhang et al., 2023).

5.4. Drivers of connectedness among oil-based commodities

Previous research confirmed the unprecedented effect of geopolitical events on connectedness changes compared with other types of shocks. To shed more light on the specific impact of geopolitical risk and other factors on connectedness, we regress all three regimes of connectedness (0.05, 0.50, and 0.95 connectedness quantiles) on a set of regressors related to geopolitical risk, credit risk, and monetary and economic conditions.

The rationale behind this analysis stems from the propagation of geopolitical risk. Investor actions are heavily impacted by uncertainty, especially during periods of political turmoil. In such instances, investors reallocate their portfolios due to increased uncertainty about the future effects on their assets, thereby influencing commodity markets (Kočenda and Moravcová, 2024). Furthermore, during these disruptions, concerns over potential portfolio devaluations lead to a marked increase in credit risk and market stress (Menkhoff et al., 2012), significantly affecting connectedness. Heightened risk aversion amplifies transmission effects (Tran, 2019), as investors aim to safeguard against possible adverse revaluations (Camanho et al., 2022). Additionally, as noted by Della Corte et al. (2022), market volatility is influenced by carry trades, which are directly impacted by interest rates. These dynamics directly shape national economic conditions, altering economic activity and further escalating volatility transmission (Davis et al., 2022; Albrecht and Kočenda, 2024).

To conduct our analysis, we employ the following regression that we estimate by the OLS with heteroskedasticity-consistent (robust) standard errors:

$$Conn_t^q = \alpha + \beta_1 GPR_t + \beta_2 US_CDS_t + \beta_3 SP500_t + \beta_4 US5Y_t + \varepsilon_t, \quad (6)$$

where *Conn* represents the value of the connectedness index at a specific quantile q . We distinguish among three quantiles, 0.05, 0.50, and 0.95, to quantify connectedness during distress, normal, and optimistic market conditions, respectively. *GPR* represents the extent of geopolitical risk, *US_CDS* (a 5-year U.S. credit default swap) is a proxy for credit risk (Menkhoff et al., 2012), *SP500* (value of the stock index S&P 500) quantifies economic activity (Davis et al., 2022), and *US5Y* (a U.S. 5-year government bond yield) is a proxy for monetary policy stance. Summary statistics, correlation matrices, and ADF unit root test results are reported in Appendix Tables A8, A9, and A11.

Our findings in Table 6 reveal several key insights. First, the role of geopolitical risk is significant for all three quantiles of connectedness, albeit with different magnitudes. The effect is positive and stronger for the lower quantile and standard connectedness. This suggests that rising geopolitical tensions are linked to increased connectedness during extreme distress and standard market conditions. Although the coefficient values associated with geopolitical risk (*GPR*) are relatively small (0.02 and 0.04 for extreme distress and standard connectedness, respectively), our detailed inspection revealed that the *GPR* values increased by as much as 400 points during major geopolitical events. In this context, the impact of geopolitical risk becomes highly pronounced as connectedness increases substantially by up to 20 percentage points.

A qualitatively similar finding is associated with an increase in credit risk. Table 6 shows that credit risk affects connectedness during distress and standard market conditions; the effect is not statistically significant during periods of positive market sentiment. An increase in credit risk (by 1%) leads to almost a double increase in connectedness. The finding aligns with those of Menkhoff et al. (2012), who showed the impact of credit risk on currency rates.

Furthermore, economic activity is inversely linked to connectedness, albeit only during distressed market conditions. This means that improved economic activity leads to decreased connectedness, whereas an economic downturn is followed by an increase in connectedness. This relationship can be interpreted through the lens of market confidence and investor behavior. During periods of economic expansion, market participants tend to exhibit more differentiated expectations and investment strategies, which reduces co-movement across commodity markets. In contrast, economic downturns are often accompanied by heightened uncertainty and risk aversion, prompting a flight to safety and more synchronized market reactions, thereby increasing connectedness.

The role of geopolitical risk further reinforces this dynamic. Although the estimated coefficients for GPR Index appear modest in magnitude, the substantial spikes in geopolitical

risk during major events—such as conflicts or sanctions—trigger abrupt shifts in investor sentiment and risk pricing. These shocks lead to a rapid alignment of asset behavior, particularly in energy commodities, which are highly sensitive to geopolitical developments. The observed increase in connectedness by up to 20 percentage points during such episodes underscores the non-linear and regime-dependent nature of volatility transmission.

Similarly, the positive association between credit risk and connectedness during distress and normal conditions reflects the systemic implications of deteriorating credit conditions. As credit risk rises, financial institutions may simultaneously adjust their exposures, reduce leverage, or rebalance portfolios in similar directions, thereby amplifying co-movements across markets. The absence of a significant effect during positive sentiment regimes suggests that credit risk becomes a binding constraint primarily in stressed environments, when liquidity and funding pressures are more pronounced.

Extending this perspective to broader economic fundamentals, we find that economic activity plays a critical role in shaping connectedness. Specifically, our results reveal that stronger economic performance, proxied by the S&P 500 index, is linked to markedly lower connectedness values, particularly during periods of distress. As shown in Table 6, a one percent increase in economic activity leads to an almost threefold (2.79) decrease in connectedness. It suggests that during economic expansions, markets exhibit more heterogeneous responses and diversified risk-taking, which mitigates systemic co-movements. Conversely, downturns in economic activity, often exacerbated by geopolitical tensions as documented by Davis et al. (2022), coincide with increased synchronization across commodity markets, elevating systemic vulnerabilities.

Complementing the role of economic fundamentals, our results also reveal the stabilizing function of credible monetary policy. We document that tighter monetary conditions, captured by increases in the U.S. 5-year Treasury yield, are associated with statistically significant reductions in volatility connectedness across all three market regimes. The effect likely reflects a normalization of risk pricing, diminished speculative pressures, and anchored investor expectations, particularly within commodity markets that are sensitive to shifts in interest rates and global liquidity. Notably, this dampening influence of monetary tightening is most pronounced during periods of extreme distress and standard market conditions. Specifically, a one percent rise in the 5-year Treasury yield leads to nearly a twofold decline in connectedness, highlighting the role of monetary policy as a direct instrument for mitigating systemic spillovers.

Taken together, these results deepen our understanding of how macro-financial conditions interact with geopolitical shocks to influence volatility connectedness. They illustrate that strong economic performance and credible monetary frameworks jointly contribute to lower systemic interdependencies, thereby constraining the channels through which shocks can propagate across markets. In this broader context, our analysis reveals that geopolitical risk remains a dominant driver of heightened connectedness among oil-based commodities, particularly during periods of market distress. The elevated co-movement under such scenarios signals intensified systemic stress, which undermines the benefits of diversification and facilitates the transmission of adverse shocks throughout the financial system. Moreover, we find that deteriorating macro-financial conditions, manifested in slowing economic activity and widening credit spreads, further compound these dynamics by creating feedback loops that exacerbate market instability. Importantly, our evidence underscores that geopolitical shocks do not operate in isolation; instead, they interact closely with underlying economic and financial variables, collectively shaping the extent to which volatility is propagated across commodity markets and beyond. It highlights the critical importance of maintaining robust macroeconomic fundamentals and credible monetary policies as tools to mitigate the systemic transmission of geopolitical and financial shocks, ultimately safeguarding both market stability and broader economic resilience.

5.5. Financial impact of geopolitical risk via connectedness: Multivariate portfolios

In Section 5.2, we identified four geopolitical risk events that persistently affected the connectedness between the four energy-based commodities. We now quantify and document the impact of geopolitical risk in financial and economic terms. As confirmed in previous research (e.g., Baruník and Ellington, 2024), some events have a persistent effect on changes in the weights of individual assets in portfolios. Kočenda and Moravcová (2024) also tracked these changes for energy-based commodities. However, they considered only portfolios with two variables. Moreover, they did not investigate portfolio changes in the context of geopolitical risk. Often, portfolio managers hold multiple similar assets in a portfolio, which is why Broadstock et al. (2022) created a method for computing multivariate portfolios. On the other hand, multivariate portfolios have not yet been computed for commodities owing to the novelty of the technique, and for that reason, we compute them in this section. Additionally, we shed light on how the geopolitical risks retrieved in Section 5.2 affected changes in the portfolio.

Tables A2–A7 and Figures 3 and 4 systematically document the adjustments in portfolio allocations in response to major market events. These changes elucidate the fluctuations in the weighting of individual assets within a portfolio predominantly comprising energy-based commodities. Specifically, the data indicate that the first day of the reopening of major U.S. trading markets after 11/09 triggered a substantial increase in the allocation of oil, which surged from 30% to 40%. Concurrently, the allocation for gasoline markedly decreased from 20% to 3% (refer to Tables A2 and A3). Notably, oil experienced a pronounced upwards trend during this period (Strejcek et al., 2021), likely contributing to its augmented portfolio presence.

Subsequently, beginning on March 13, 2014, the announcement of Crimea’s autonomy triggered notable rebalancing within the portfolio, particularly between diesel and oil. The allocation of oil sharply decreased from 40% to 4%, which was predominantly offset by a substantial increase in the weight of diesel (Tables A3 and A4). The shift underscores the significant impact of the announcement of Crimea’s autonomy on the oil market, whereas diesel prices remained relatively stable. Notably, this research represents the inaugural documentation of the effect of geopolitical risk on volatility connectedness, specifically highlighting the spillover effects of portfolio capital reallocating from oil to diesel.

A significant event took place on May 29, 2015, profoundly influencing portfolio allocations through yield transmission mechanisms, with a particularly notable impact on the diesel, heating oil, and gasoline markets. The event notably increased the portfolio weight of heating oil from 3% to 34% and that of gasoline from 6% to 8%, primarily at the expense of diesel, which decreased its weight from 87% to 49% (Tables A4 and A5). The transmissions were affected by a political shift in Nigeria (oil-rich Rivers State) during the first-ever democratic transfer between two political parties on May 29 (Payne, 2015). The shock marked a pivotal decline in diesel's prominence, leading to a persistent shift in its portfolio allocation. Our study is especially valuable for documenting events that have led to lasting changes in the distribution of key energy commodities in the context of events with geopolitical backgrounds.

The decline in the weight of diesel within portfolios was further exacerbated by Russia’s invasion of Ukraine in February 2022. In this context, the valuation of diesel plummeted to an all-time low of 17%, potentially attributable to initiatives aimed at substituting energy-based commodities with more environmentally sustainable alternatives (Priya et al., 2022). Concurrently, as documented in Tables A5 and A6, portfolio allocation for crude oil surged, with its value reaching unprecedented highs due to escalating concerns over potential disruptions in the oil supply that passed through Ukraine (Albrecht et al., 2025). Specifically, the weight of crude oil in the portfolio increased from 13% to 72% (refer to Tables A5 and A6).

The dynamic shifts in these portfolio weights are further illustrated in Figures 3 and 4. Our study represents a pioneering effort in documenting multivariate changes in commodity portfolios, with increases of 20% or more underscoring the profound impact of these geopolitical events on portfolio management strategies.

5.6. *Financial impact of commodity-market connectedness on banks with high exposure to oil commodities*

Oil and oil-based commodities price fluctuations heavily affect most economic activities, as shown in recent macroeconomic evidence (Kang and Ratti, 2013a; Togonidze & Kočenda, 2022). As we have demonstrated earlier, the price fluctuations driven by geopolitical risk have a significant impact on the connectedness among commodities, which alters the transmission of shocks across markets. Specifically, we now emphasize that banks with high exposure to oil-based commodities serve as critical transmission channels through which systemic shocks, originating from geopolitical risk and reflected in commodity market connectedness, can propagate into the broader financial system. The framing aligns with recent findings in the literature (e.g., Balli, 2023), which underscore the importance of sectoral vulnerabilities in amplifying systemic risk. The link between energy commodity market connectedness and geopolitical risk is likely further intensified by the lending activities of multinational banks that maintain substantial exposures to oil and oil-based commodities (Kang and Ratti, 2013b). The transmission channel highlights how banks' lending relationships with multinational firms, which are themselves susceptible to trade fragmentation and uncertainty shocks, can exacerbate systemic vulnerabilities.

Moreover, multinational banks are associated with heightened instability in lending activities, as extreme global events and systemic shocks can rapidly alter foreign banks' lending patterns. These impacts ultimately materialize in bank performance (Hesse and Poghosyan, 2016; Katircioglu et al., 2018; Lee and Lee, 2019; Çikiryel et al., 2024). Banks with significant exposure to oil commodities must therefore actively account for the volatilities of these markets and their spillovers, captured by connectedness, by adopting robust hedging strategies to protect their profitability. By focusing on tail-connectedness and its asymmetric effects under extreme market conditions, we examine how both heightened synchronization during distress and excessive idiosyncrasy during optimistic periods can affect banks' profitability. The perspective provides a novel link between commodity market interdependencies, financial sector stability, and macro-financial resilience.

To empirically capture these dynamics, we model the financial impact of connectedness on the profitability of banks with high exposure to oil-based commodities by estimating the following OLS specification with heteroskedasticity-consistent (robust) standard errors:

$$BankProfitability_{it} = \alpha + \beta_1 Conn_t^q + \sum_{m=1}^M \beta_m banks_{it}^m + \sum_{s=1}^S \beta_s macro_t^s + \gamma EPU_t + \mu_i + \theta_t + \varepsilon_{it}, \quad (7)$$

In the above specification, bank performance is captured by the profitability of individual banks, measured as the Return on Average Equity (ROAE), where i denotes the bank with high exposure to oil, and t indicates the specific year. The first explanatory variable is connectedness at three different quantiles (q) that represent periods of extreme distress ($q = 0.05$), normal market conditions ($q = 0.50$), and positive market sentiment ($q = 0.95$). In specification (7), we further control for bank-specific characteristics ($banks$) directly tied to individual banks. Based on the literature, these determinants encompass solvency (ratio of equity to assets), bank-specific credit risk (non-performing loans, NPL), and capital (Tier 1-based capital adequacy ratio). We also control for macroeconomic conditions ($macro$) by using the following variables, which are standard in the literature: global real GDP growth, global inflation (CPI), the U.S. real effective exchange rate (REER), and interest rate (proxied by 3-month U.S. treasury bill yield). The global economic policy uncertainty (EPU) index is employed to capture global uncertainty, which affects banks through several well-documented transmission channels. The key channels include heightened earnings opacity via increased discretionary provisioning and reduced accounting conservatism (Jin et al., 2019), diminished bank stability through elevated insolvency risks, particularly mitigated by regulatory frameworks (Nguyen, 2021), and non-linear effects on bank resilience shaped by institutional quality and market competition (Shabir et al., 2021). All series were subjected to unit-root tests; variables found to be non-stationary enter the regression in first differences (denoted Δ in the table). In the panel regression model, we incorporate bank fixed effects (μ_i) and time effects (θ_t); residuals are captured in ε_{it} . Summary statistics, correlation matrices, and ADF unit root test results are reported in Appendix Tables A8, A10, and A11.

We report estimation results in Table 7 under varying market conditions represented by three quantiles (0.05, 0.50, and 0.95) that correspond to extreme distress, standard market conditions, and positive sentiment, respectively. From the table, we can gauge the complex impact of connectedness on bank profitability while controlling for macroeconomic conditions

and bank-specific characteristics. Under extreme distress ($\tau = 0.05$), connectedness negatively impacts profitability, indicating that heightened systemic spillovers across markets erode banks' profit margins during turbulent times. Macroeconomic variables, such as GDP growth and CPI, positively contribute to profitability, reflecting the stabilizing role of economic expansion and inflation adjustments. Conversely, higher interest rates and elevated NPL levels significantly reduce profitability, underscoring the challenges banks face in managing credit risks and funding costs during adverse market conditions. During periods of standard market conditions ($\tau = 0.50$), the connectedness coefficient is statistically insignificant, reflecting moderated systemic risks. The effect of macroeconomic indicators like GDP and CPI remains positive, though less pronounced compared to distress periods. Interest rates and NPL levels still hamper profitability, though their influence is less acute than in distressed market conditions. Even in optimistic market conditions ($\tau = 0.95$), connectedness negatively affects profitability. The ever-present geopolitical risk (as demonstrated in previous sections) might work as a latent danger looming in the background, but the negative impact might also be likely due to competitive pressures and market dynamics under the positive sentiment. Macroeconomic factors like GDP growth and CPI continue to support profitability. However, the adverse impact of interest rates and NPL persists, albeit at a reduced magnitude when compared to distress and standard market conditions.

The key evidence based on the results in Table 7 indicates that bank profitability is (i) negatively affected by connectedness, independently of the distress or optimistic market conditions ($\tau=0.05$ or $\tau=0.95$), and (ii) in contrast, profitability does not appear to be influenced by connectedness under standard market conditions ($\tau=0.50$). We argue that the detrimental effect of tail-connectedness on bank profitability during both extreme conditions stems from its unique risk characteristics present at both extremes of the return distribution. During distress (downside), increased co-movement among commodity markets intensifies systemic vulnerabilities because the benefits of diversification diminish when asset returns become highly correlated during periods of financial distress (as previously outlined by Zhou et al. (2024)). This convergence undermines conventional risk mitigation techniques and exposes banks to concentrated losses (downside exposure). Such behavior is in line with previous findings of Claessens and van Horen (2014) and Fidrmuc and Kapounek (2019). These patterns are also consistent with our findings in Section 5.5, where geopolitical shocks led to substantial shifts in multivariate portfolio allocations across energy commodities. Such portfolio adjustments underscore how heightened connectedness reshapes investment strategies and reinforces the systemic channels through which commodity market dynamics influence

financial institutions. Conversely, during overly optimistic conditions (upside), excessively low connectedness implies that energy commodities behave in a highly idiosyncratic manner, which makes it more difficult for banks to anticipate correlations and construct reliable hedging strategies. The unpredictability of inter-commodity relationships elevates uncertainty, reduces the efficiency of portfolio optimization (Su and He, 2024), and, as a result, erodes profitability (Hou and Pan, 2022). In contrast, during standard market conditions, neither downside nor upside risks are present in their extreme forms, and profitability is not affected by them. Our findings underscore the importance of accounting for tail dynamics in risk management frameworks, particularly for banks with significant exposure to commodity-linked assets.

Finally, the geopolitical risk propagates via connectedness (as demonstrated in Section 5.4) but the transmission mechanism of systemic spillovers, captured by quantile connectedness, is more complicated. Connectedness quantifies shocks that propagate across markets and increase uncertainty. Elevated connectedness destabilizes borrowers' financial health, leading to higher non-performing loans (NPLs), a direct measure of credit risk that erodes banks' profitability by increasing loan loss provisions. Concurrently, spillovers strain liquidity management as banks hold larger reserves to mitigate funding risks, reducing their ability to generate income. Macroeconomic conditions such as GDP growth and inflation act as stabilizing forces by improving repayment capacity and enhancing interest earnings, while higher interest rates increase funding costs and reduce loan demand, negatively affecting profitability. Bank-specific factors like solvency and capital adequacy play a dual role, with higher capital acting as a buffer against shocks. In contrast, weak solvency amplifies the adverse effects of systemic and macroeconomic stressors. These interconnected pathways collectively illustrate how systemic risks, macroeconomic dynamics, and internal bank characteristics converge to shape bank profitability.

6. Conclusion

Our study provides a comprehensive and novel analysis of the impact of geopolitical risk on volatility connectedness among oil-based energy commodities, addressing both persistent and transitory impacts of geopolitical risk. Utilizing a quantile-based framework, we assess how the propagation of volatility differs across varying market conditions, ranging from extreme distress to periods of positive sentiment. In line with seminal research on asset connectedness, our findings confirm that volatility transmissions are not uniform but depend heavily on the

state of the market. Specifically, heating oil and crude oil emerge as dominant transmitters of volatility, particularly during periods of turmoil.

Our study breaks new ground by being the first to explicitly distinguish between transitory and persistent effects of geopolitical shocks on volatility connectedness in the energy sector. While previous studies have acknowledged the role of market events in influencing volatility (Baruník and Ellington, 2024), we go a step further by identifying four specific shocks that led to persistent shifts in connectedness: the 9/11 attacks, the Crimea crisis, Nigeria's political shift and Russia's invasion of Ukraine. These events persistently altered the connectedness structure among key commodities by at least 5%, providing robust empirical evidence that these systemic shocks had lasting effects on market dynamics. Our findings contribute to the growing literature on systemic risk and its persistence, with direct implications for risk management and asset allocation.

Furthermore, we quantify the impacts of geopolitical risk shocks in financial terms. First, we perform multivariate portfolio analysis on the basis of the work of Broadstock et al. (2022) by applying dynamic portfolio allocation techniques to energy commodities in response to these shocks. The shifts in portfolio weights—such as a 20% reallocation from gasoline to crude oil following geopolitical events—underscore the importance of dynamically adjusting portfolio strategies in the face of systemic risk. The analysis aligns with the literature on minimum connectedness portfolios, emphasizing the need for active portfolio management when facing both transitory and persistent market disruptions. Second, we demonstrate that geopolitical risk transmits uncertainty to the markets under both distressed and optimistic conditions since the connectedness negatively affects the profitability of ten global banks highly exposed to oil-based commodities. Those banks have to hedge, with suitable portfolios, against volatility in the oil market to protect their performance. However, the detrimental effect of tail-connectedness during both extreme conditions erodes banks' profitability due to reduced efficiency of portfolio optimization. Our results accentuate the impacts of tail dynamics in risk management, especially for banks with high exposure to oil-linked assets.

Our study contributes to the growing body of literature on volatility connectedness, systemic risk, and geopolitical risk by introducing several novel elements. We offer a unique examination of how different geopolitical conditions influence volatility transmission, identify persistent shifts in connectedness due to geopolitical shocks, and highlight their implications for global stability and economic policy. Moreover, we explore the role of geopolitical risk in shaping connectedness and its impact across various market regimes, with a focus on sentiment-driven dynamics. The findings are particularly relevant for policy-makers and analysts seeking

to understand and mitigate the effects of geopolitical risk on energy markets, where the interplay between transitory and persistent shocks significantly influences market stability. This research provides a framework for better understanding the dynamics of connectedness in the context of geopolitical risk, echoing broader discussions about the need for proactive strategies in an increasingly uncertain global environment.

Finally, by being the first study to examine changes in multivariate portfolios of oil-based energy commodities under varying geopolitical regimes, we provide valuable insights for analysts seeking to optimize portfolio allocation in the presence of dynamic connectedness structures. Such a perspective enhances the understanding of how short-term and long-term shifts in interdependence affect risk-adjusted returns and diversification strategies. In addition, our finding that the profitability of systemically important banks, linked to the oil industry, is influenced by the tail-connectedness of commodity markets suggests important regulatory implications. Specifically, policy-makers may consider incorporating commodity-linked stress scenarios into macroprudential frameworks or designing capital requirements that reflect banks' exposure to commodity-driven systemic risk. Such measures could strengthen financial system resilience in the face of geopolitical uncertainty and commodity market volatility.

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Table 1 Static quantile connectedness (lower quantile ($\tau = 0.05$) – extreme distress)

tau = 0.05	Gasoline	Oil	Heating oil	Diesel	FROM
Gasoline	55.10	20.21	13.66	11.03	44.90
Oil	18.04	48.91	20.68	12.37	51.09
Heating oil	12.35	20.85	49.18	17.63	50.82
Diesel	11.08	14.03	19.29	55.59	44.41
TO	41.47	55.09	53.63	41.02	191.22
Inc. Own	96.57	104.00	102.81	96.61	cTCI/TCI
NET	-3.43	4.00	2.81	-3.39	63.74/47.80

Notes: Table 1 presents the static quantile connectedness matrix for the lower quantile ($\tau = 0.05$), corresponding to periods of extreme distress among energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel). The rows indicate how much each commodity is affected by others ("FROM"), while the columns reflect how much each commodity affects the others ("TO"). The "Inc. Own" column represents the total connectedness, including a commodity's own effect. The net connectedness ("NET") shows whether a commodity is a net transmitter or receiver of shocks. TCI quantifies the overall level of interconnectedness in the system, measuring the extent to which shocks in one commodity spill over to others under the conditions represented by the 0.05 quantile.

Table 2 Static quantile connectedness (medium quantile ($\tau = 0.50$) - standard market conditions)

tau = 0.50	Gasoline	Oil	Heating oil	Diesel	FROM
Gasoline	62.32	17.21	10.16	10.32	37.68
Oil	15.39	53.11	18.71	12.79	46.89
Heating oil	10.13	20.33	51.50	18.05	48.50
Diesel	10.27	12.86	18.08	58.79	41.21
TO	35.79	50.39	46.94	41.16	174.27
Inc. Own	98.11	103.50	98.44	99.95	cTCI/TCI
NET	-1.89	3.50	-1.56	-0.05	58.09/43.57

Notes: Table 2 presents the static quantile connectedness matrix for the standard quantile ($\tau = 0.50$), corresponding to median/normal market conditions among energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel). The rows indicate how much each commodity is affected by others ("FROM"), while the columns reflect how much each commodity affects the others ("TO"). The "Inc. Own" column represents the total connectedness, including a commodity's own effect. The net connectedness ("NET") shows whether a commodity is a net transmitter or receiver of shocks. TCI quantifies the overall level of interconnectedness in the system, measuring the extent to which shocks in one commodity spill over to others under the conditions represented by the 0.50 quantile.

Table 3 Static quantile connectedness (upper quantile ($\tau = 0.95$) – positive sentiment)

tau = 0.95	Gasoline	Oil	Heating oil	Diesel	FROM
Gasoline	27.55	26.57	21.67	24.21	72.45
Oil	27.55	26.57	21.67	24.21	73.43
Heating oil	27.55	26.57	21.67	24.21	78.33
Diesel	27.55	26.57	21.67	24.21	75.79
TO	82.65	79.70	65.01	72.64	300.00
Inc. Own	110.21	106.27	86.67	96.85	cTCI/TCI
NET	10.21	6.27	-13.33	-3.15	100.00/75.00

Notes: Table 3 presents the static quantile connectedness matrix for the upper quantile ($\tau = 0.95$), corresponding to periods of extreme positive market sentiment among energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel). The rows indicate how much each commodity is affected by others ("FROM"), while the columns reflect how much each commodity affects the others ("TO"). The "Inc. Own" column represents the total connectedness, including a commodity's own effect. The net connectedness ("NET") shows whether a commodity is a net transmitter or receiver of shocks. TCI quantifies the overall level of interconnectedness in the system, measuring the extent to which shocks in one commodity spill over to others under the conditions represented by the 0.95 quantile.

Table 4 Empirical probabilities of increased connectedness following specific events

Title	Type	Date	D+0	D+1	D+2	D+3	D+4
Iraq Bombs Five Huge Tankers at Iran Oil Site	missile	16.5.1988	1.00	1.00	1.00	1.00	1.00
Geneva Peace Conference	political	9.1.1991	1.00	1.00	1.00	1.00	1.00
Soviet coup d'état attempt	political	19.8.1991	1.00	1.00	1.00	1.00	1.00
Venezuela: coup against government	political	27.11.1992	0.59	1.00	1.00	1.00	1.00
Oil-for-Food Programme	political	20.5.1996	1.00	1.00	1.00	1.00	1.00
The warship explosion: the overview; blast kills sailors on U.S. ship in Yemen	missile	12.10.2000	0.88	0.99	0.99	0.99	0.99
Iraq agrees that the UN resolution about its disarmament is enforced	peace	27.11.2002	0.50	1.00	1.00	1.00	1.00
Start of the ground invasion in Iraq by the U.S.-led coalition	war	20.3.2003	0.90	1.00	1.00	1.00	0.99
Bomb attack on UN headquarters in Iraq kills the agency's top envoy Sergio Vieira de Mello and 21 other employees	missile	19.8.2003	0.35	1.00	1.00	1.00	1.00
Arab Spring: Half of Libya oil production shut down	strike	23.2.2011	0.79	1.00	0.99	1.00	0.99
North Korea Says It 'Enters War' Against South Korea	threat	1.4.2013	0.41	1.00	1.00	1.00	1.00
Iraq confirms oil refinery loss	war	23.6.2014	0.49	1.00	1.00	1.00	1.00
Kremlin Battles National Oil Companies	political	27.9.2023	1.00	1.00	1.00	1.00	1.00

Notes: The table presents thirteen geopolitical events that surpassed the standard statistical significance threshold. The D+0 to D+4 columns display the percentage of the 1000 bootstrapped values that exceed the previous mean value. These events demonstrate a significant impact as they surpass the threshold from 1 to 4 days post-event, equivalent to one trading week. The effect on the event day itself is excluded to account for the speed of information dissemination across news channels.

Table 5 Events with persistent effect on connectedness

Title	Type	Date	Change in connectedness (in %)	Source
9/11 Terrorist attacks	missile	11.9.2001	5.91	https://www.jstor.org/stable/26673240?utm_source
Russian-occupied Crimea announces autonomy	political	11.3.2014	5.45	https://www.jstor.org/stable/24480487
Political shift in Nigeria's oil-rich state	political	29.5.2015	7.55	https://fundforpeace.org/wp-content/uploads/2018/08/conflictbulletin-rivers-1508.pdf?utm_
Russia invades Ukraine	war	24.2.2022	7.30	https://www.cambridge.org/core/journals/american-journal-of-international-law/article/russia-ukraine-and-the-future-world-order/A7F4BF6CE7296F4C1AA1A4C9C3C105

Table 6 Drivers of connectedness at extreme and regular market conditions

	Quantile Connectedness		
	0.05 (extreme distress)	0.50 (standard condition)	0.95 (positive sentiment)
Geopolitical risk	0.02** (0.01)	0.04** (0.02)	0.01* (0.00)
Credit risks	1.80** (0.74)	5.18*** (1.54)	0.56 (0.35)
Economic conditions	-2.79*** (1.05)	-2.57 (2.07)	0.34 (0.22)
Monetary conditions	-1.90*** (0.29)	-4.99*** (0.59)	-0.51*** (0.11)
constant	88.14*** (7.80)	81.94*** (15.45)	71.88*** (1.67)
Observations	217	217	217
R ² adj.	0.14	0.24	0.15

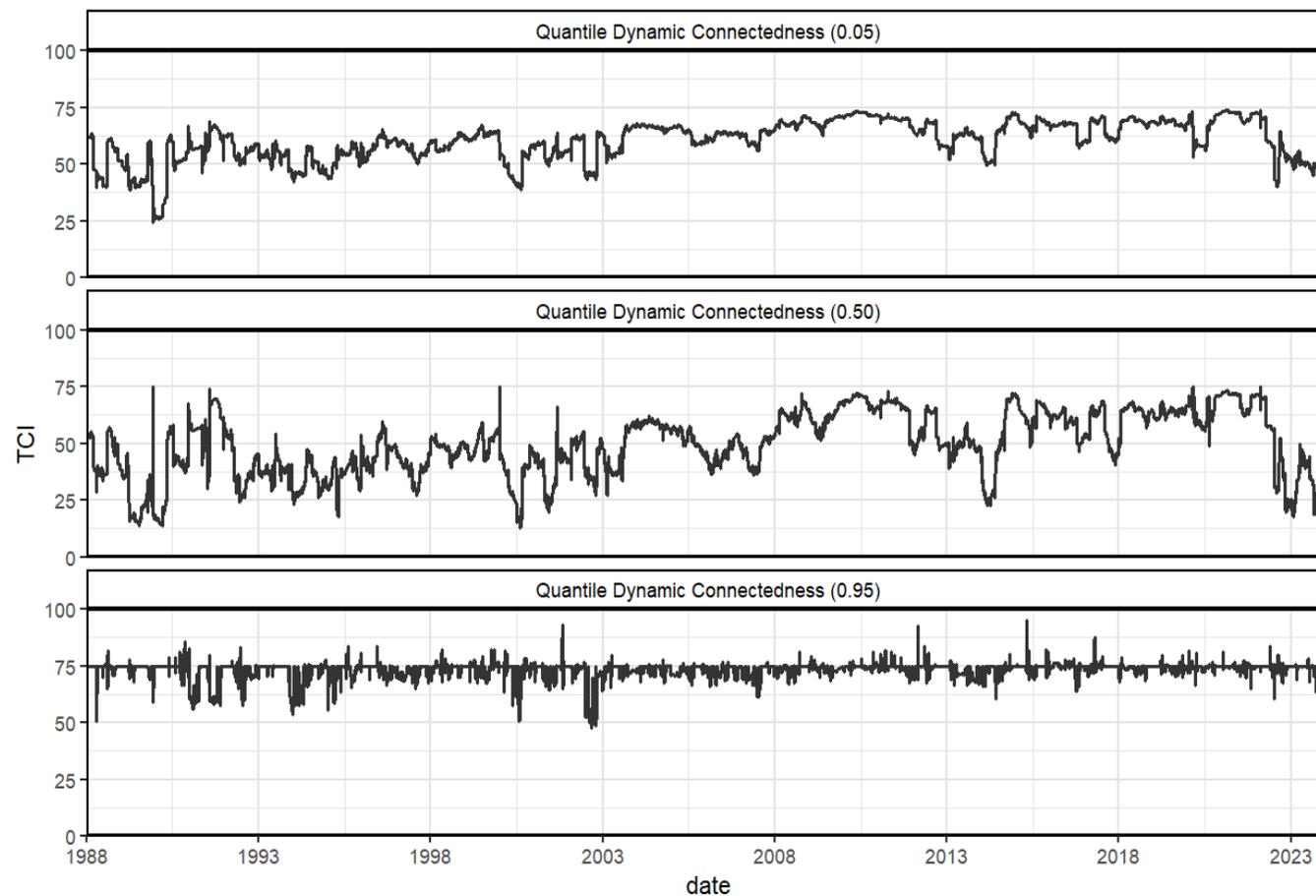
*Note: *** denotes p-value < 0.01, ** p-value < 0.05, and * p-value < 0.10. The S&P500 index is transformed by logarithms. The values in parentheses represent standard errors of the estimated coefficients. These indicate the level of statistical uncertainty around each estimate. Smaller standard errors imply more precise estimates, while larger values suggest greater variability.*

Table 7 Impact of connectedness on profitability of banks with high exposure to oil-based commodities (extreme and regular market conditions)

	Bank profitability		
	0.05 (extreme distress)	0.50 (standard conditions)	0.95 (positive sentiment)
Connectedness	-0.37* (0.05)	-0.13 (0.12)	-1.49** (0.01)
Bank-specific controls			
Solvency	24.96 (0.72)	13.48 (0.84)	10.80 (0.87)
Δ Tier 1 capital ratio	0.77* (0.02)	0.82* (0.03)	0.86* (0.03)
NPL	-0.14** (0.01)	-0.13** (0.01)	-0.13* (0.01)
Macroeconomic controls			
GDP Growth	0.95*** (0.00)	0.73** (0.00)	0.65** (0.00)
ΔCPI	1.28* (0.01)	1.09* (0.03)	0.91** (0.01)
REER	-0.06 (0.64)	-0.03 (0.81)	0.01 (0.96)
ΔInterest rate	-1.96** (0.00)	-1.50* (0.01)	-1.11* (0.04)
ΔUncertainty (EPU)	0.02** (0.01)	0.02* (0.02)	0.02** (0.01)
constant	24.22 (0.21)	4.51 (0.68)	103.44* (0.01)
Observations	134	134	134
R ² adj.	0.23	0.20	0.20

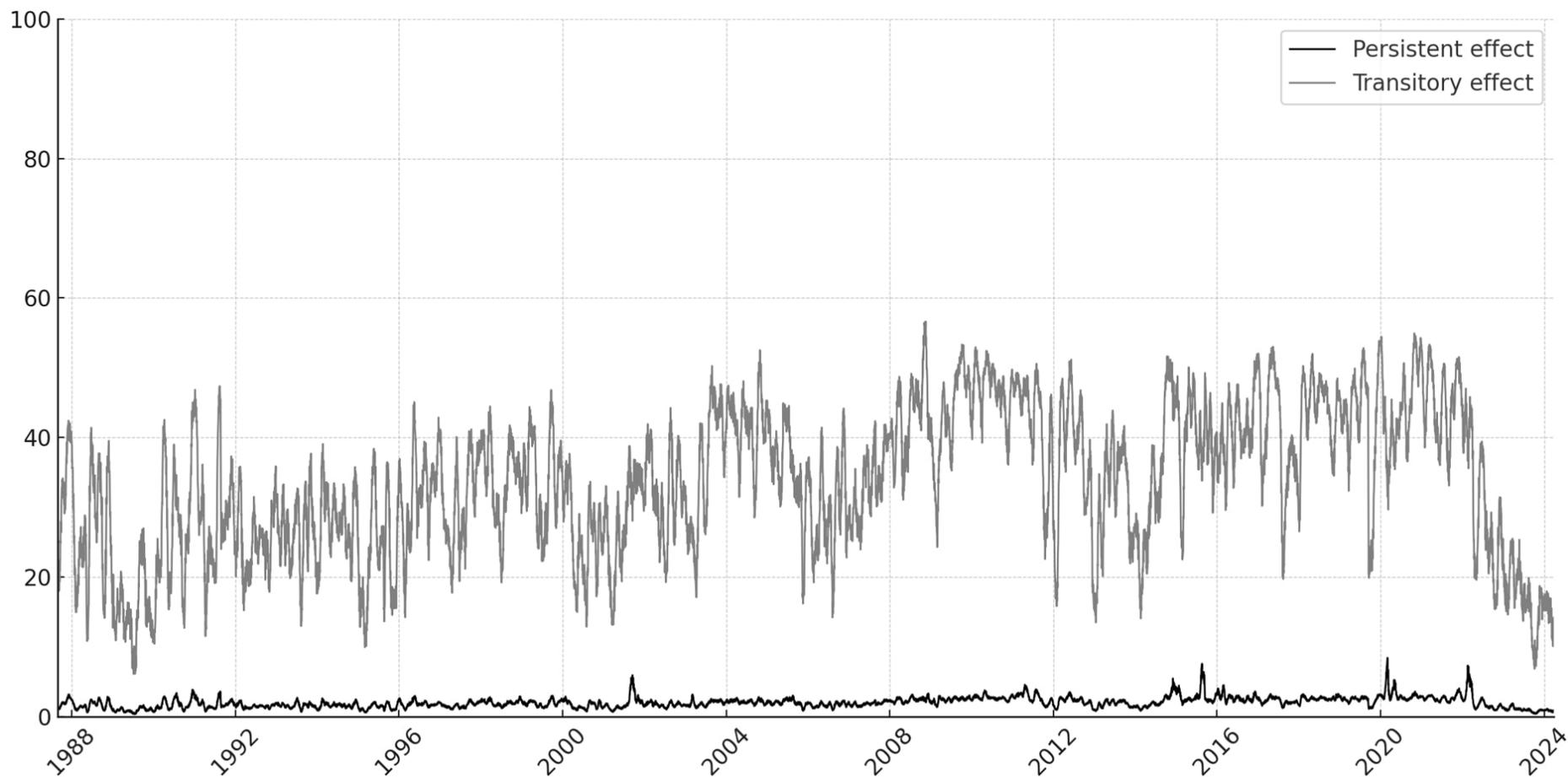
*Note: *** denotes p-value < 0.01, ** p-value < 0.05, and * p-value < 0.10. The table presents the results of panel regressions with fixed effects, examining the impact of connectedness on the profitability of banks (ROAE) with high exposure to oil-based commodities (extreme and regular market conditions) when controlling for macroeconomic conditions and bank-specific characteristics. The quantile variables (Q05, Q50, Q95) represent different market conditions, ranging from extreme distress (Q05) to positive sentiment (Q95). The bank-specific variables, such as capital (measured as TIER1 capital) and non-performing loans (NPL), reflect financial stability and credit quality, while macroeconomic indicators capture economic trends (global real GDP growth, global CPI, USD real effective exchange rate (REER), U.S. 3-month treasury bill yield). First-differencing was applied to certain variables to transform them into stationary series. The values in parentheses represent standard errors of the estimated coefficients. These indicate the level of statistical uncertainty around each estimate. Smaller standard errors imply more precise estimates, while larger values suggest greater variability.*

Figure 1 Dynamic quantile connectedness



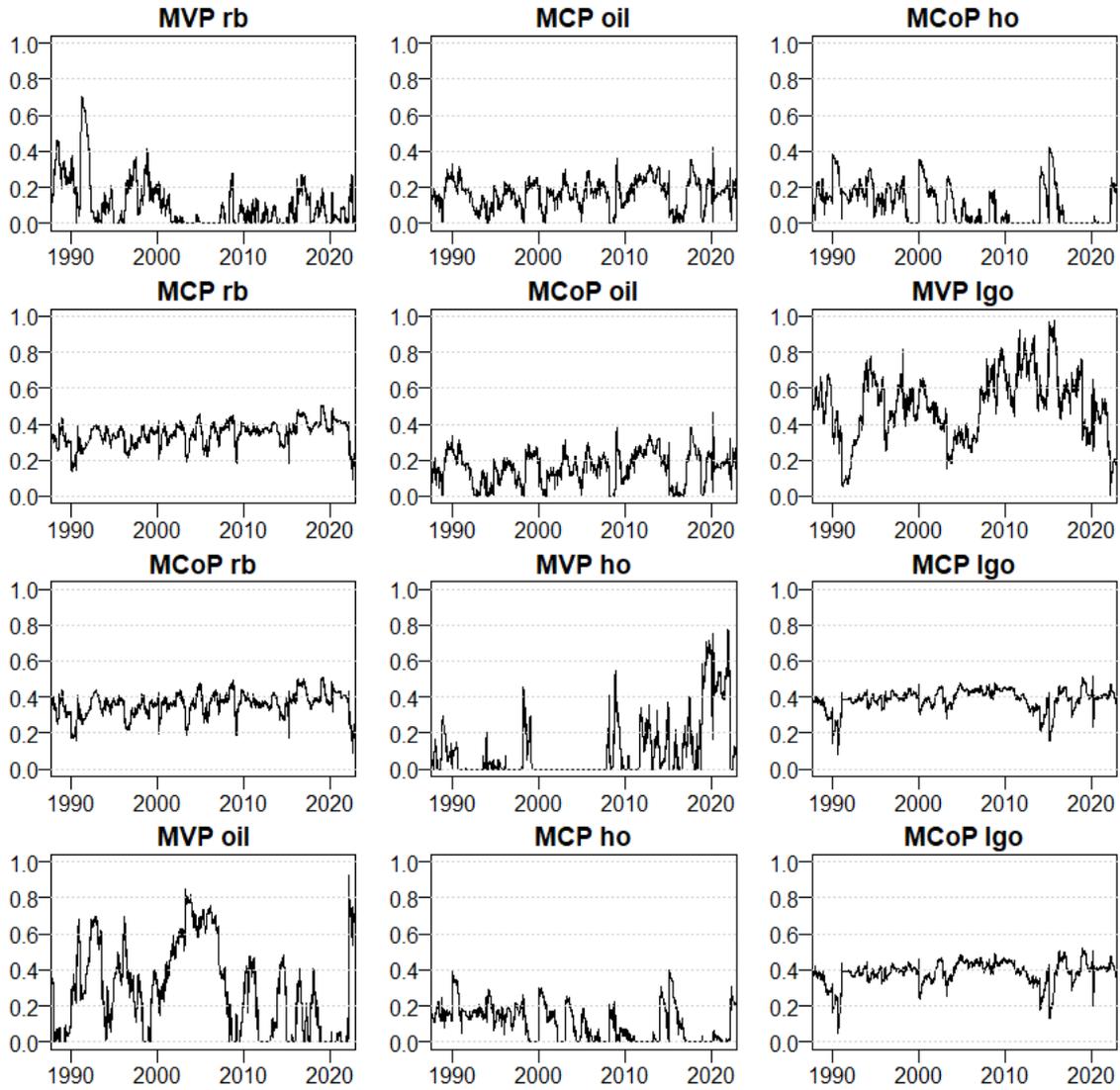
Notes: This figure presents the evolution of the total connectedness index (TCI) for quantile dynamic connectedness among the selected energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) at the 0.05 (extreme distress), 0.50 (median/normal market conditions), and 0.95 (positive market sentiment) quantiles from June 1998 to March 2024.

Figure 2 Persistent and transitory connectedness



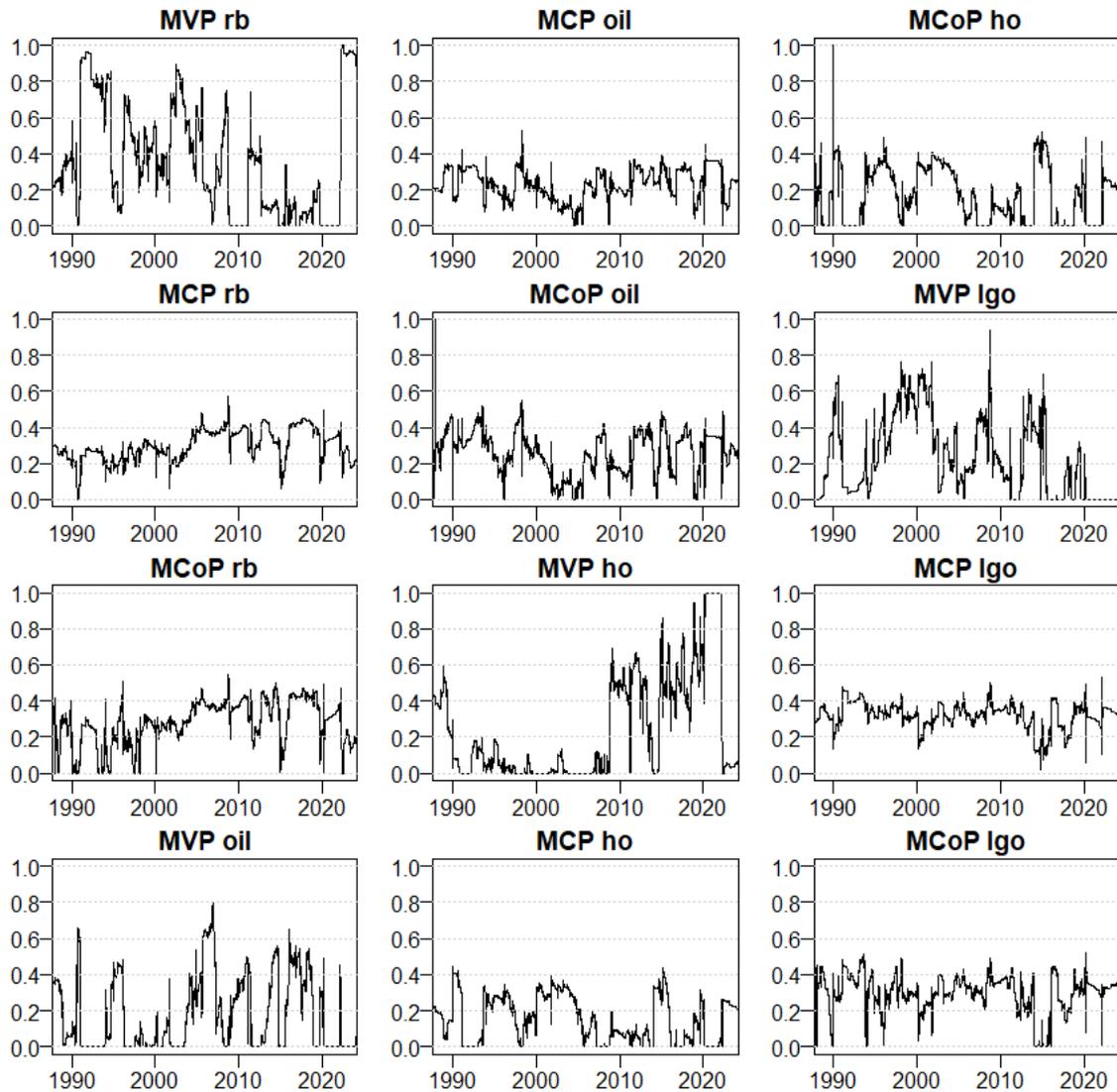
Notes: This figure plots the posterior median of horizon-specific dynamic total network connectedness from January 1998 to March 2024 for selected energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel). Transitory refers to the short-term, transitory connectedness, which we define as 1 day to 5 days; and Persistent refers to long-term, persistent connectedness, which we define as horizons > 30 days. Specific dates of the events are provided in Table 5.

Figure 3 Dynamic portfolio weights (logarithmic differences)



Notes: This figure illustrates the multivariate dynamic portfolio weights (logarithmic differences) for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) over time, from January 1998 to March 2024. The three selected dynamic portfolio strategies are the Minimum Variance Portfolio (MVP), Minimum Correlation Portfolio (MCP), and Minimum Connectedness Portfolio (MCoP).

Figure 4 Dynamic portfolio weights (realized variances)



Notes: This figure illustrates the multivariate dynamic portfolio weights (realized variances) for energy-based commodities (Gasoline - rb, Oil - oil, Heating Oil - ho, and Diesel - lgo) over time, from January 1998 to March 2024. The three selected dynamic portfolio strategies are the Minimum Variance Portfolio (MVP), Minimum Correlation Portfolio (MCP), and Minimum Connectedness Portfolio (MCoP).

Appendix

Table A1 Descriptive statistics (ln diff)

	Gasoline	Oil	Heating oil	Diesel
Mean	0.00	0.00	0.00	0.00
	-0.54	-0.51	-0.41	-0.40
Variance	0.00	0.00	0.00	0.00
Skewness	-0.81***	-1.12***	-1.24***	-1.97***
	0.00	0.00	0.00	0.00
Ex. Kurtosis	18.88***	20.85***	18.07***	36.98***
	0.00	0.00	0.00	0.00
Jarque-Bera statistic	131885.57***	161544.79***	122109.35***	507709.14***
	0.00	0.00	0.00	0.00
Elliott-Rothenberg- Stock test	-33.66	-43.26	-41.41	-20.91
	0.00	0.00	0.00	0.00
Ljung-Box statistic Q(20)	23.46***	42.44***	34.39***	80.47***
	0.00	0.00	0.00	0.00
Ljung-Box statistic Q2(20)	1189.77***	680.27***	532.67***	449.55***
	0.00	0.00	0.00	0.00
Pearson	Gasoline	Oil	Heating oil	Diesel
Gasoline	1.00***	0.74***	0.68***	0.47***
Oil	0.74***	1.00***	0.77***	0.56***
Heating oil	0.68***	0.77***	1.00***	0.60***
Diesel	0.47***	0.56***	0.60***	1.00***

Notes: Table A1 presents the descriptive statistics for the logarithmic differences (ln diff) of energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel). Jarque-Bera statistic tests for normality. Elliott-Rothenberg-Stock test is used to check for stationarity. Ljung-Box Q-statistic tests for autocorrelation in the time series.

Table A2 Multivariate portfolio

from 2.1.1998 until 17.9.2001

Minimum Variance Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.20	0.16	0.00	0.56	0.40	0.00
Oil	0.30	0.20	0.00	0.65	0.31	0.00
Heating oil	0.04	0.08	0.00	0.23	0.49	0.00
Diesel	0.47	0.17	0.09	0.68	0.41	0.00

Minimum Correlation Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.32	0.05	0.22	0.39	0.31	0.00
Oil	0.15	0.07	0.02	0.26	0.20	0.00
Heating oil	0.17	0.08	0.00	0.33	0.41	0.00
Diesel	0.36	0.06	0.25	0.42	0.31	0.00

Minimum Connectedness Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.33	0.06	0.22	0.41	0.30	0.00
Oil	0.13	0.09	0.00	0.27	0.19	0.00
Heating oil	0.17	0.08	0.00	0.33	0.40	0.00
Diesel	0.36	0.06	0.23	0.42	0.31	0.00

Notes: Table A2 presents the multivariate portfolio allocations for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) from January 2, 1998, until September 17, 2001, across three different portfolio strategies: Minimum Variance Portfolio, Minimum Correlation Portfolio, and Minimum Connectedness Portfolio

Table A3 Multivariate portfolio

from 18.9.2001 until 12.3.2014

Minimum Variance Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.03	0.05	0.00	0.12	0.51	0.00
Oil	0.40	0.27	0.00	0.78	0.27	0.00
Heating oil	0.05	0.10	0.00	0.29	0.37	0.00
Diesel	0.51	0.19	0.22	0.80	0.25	0.00

Minimum Correlation Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.35	0.05	0.25	0.43	0.43	0.00
Oil	0.18	0.07	0.00	0.29	0.14	0.00
Heating oil	0.05	0.07	0.00	0.21	0.26	0.00
Diesel	0.41	0.04	0.33	0.46	0.12	0.00

Minimum Connectedness Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.37	0.05	0.26	0.45	0.42	0.00
Oil	0.18	0.08	0.00	0.30	0.13	0.00
Heating oil	0.04	0.07	0.00	0.21	0.26	0.00
Diesel	0.41	0.04	0.33	0.46	0.11	0.00

Notes: Table A3 presents the multivariate portfolio allocations for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) from September 18, 2001, until March 12, 2014, across three different portfolio strategies: Minimum Variance Portfolio, Minimum Correlation Portfolio, and Minimum Connectedness Portfolio.

Table A4 Multivariate portfolio

from 13.3.2014 until 20.8.2015

Minimum Variance Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.06	0.04	0.00	0.10	0.54	0.00
Oil	0.04	0.06	0.00	0.15	0.53	0.00
Heating oil	0.03	0.06	0.00	0.18	0.56	0.00
Diesel	0.87	0.05	0.78	0.93	0.06	0.01

Minimum Correlation Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.34	0.03	0.29	0.39	0.40	0.00
Oil	0.10	0.05	0.05	0.21	0.37	0.00
Heating oil	0.29	0.08	0.13	0.39	0.42	0.00
Diesel	0.28	0.06	0.18	0.38	-0.25	0.00

Minimum Connectedness Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.35	0.04	0.28	0.41	0.39	0.00
Oil	0.08	0.06	0.02	0.23	0.37	0.00
Heating oil	0.31	0.09	0.12	0.41	0.41	0.00
Diesel	0.26	0.07	0.15	0.39	-0.25	0.00

Notes: Table A4 presents the multivariate portfolio allocations for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) from March 13, 2014, until May 28, 2015, across three different portfolio strategies: Minimum Variance Portfolio, Minimum Correlation Portfolio, and Minimum Connectedness Portfolio.

Table A5 Multivariate portfolio

from 29.5.2015 until 24.2.2022

Minimum Variance Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.08	0.07	0.00	0.23	0.53	0.00
Oil	0.09	0.13	0.00	0.37	0.31	0.00
Heating oil	0.34	0.22	0.00	0.68	0.14	0.00
Diesel	0.49	0.11	0.30	0.67	0.15	0.00

Minimum Correlation Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.42	0.03	0.36	0.47	0.44	0.00
Oil	0.16	0.08	0.02	0.30	0.19	0.00
Heating oil	0.01	0.02	0.00	0.05	-0.02	0.38
Diesel	0.41	0.04	0.32	0.48	0.00	0.98

Minimum Connectedness Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.42	0.04	0.35	0.49	0.44	0.00
Oil	0.16	0.09	0.00	0.32	0.19	0.00
Heating oil	0.00	0.01	0.00	0.01	-0.02	0.46
Diesel	0.42	0.05	0.32	0.50	0.00	0.86

Notes: Table A5 presents the multivariate portfolio allocations for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) from May 29, 2015, until February 24, 2022, across three different portfolio strategies: Minimum Variance Portfolio, Minimum Correlation Portfolio, and Minimum Connectedness Portfolio.

Table A6 Multivariate portfolio

since 25.2.2022 until 28.3.2024

Minimum Variance Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.06	0.07	0.00	0.18	0.37	0.00
Oil	0.72	0.04	0.63	0.77	0.12	0.00
Heating oil	0.04	0.04	0.00	0.10	0.59	0.00
Diesel	0.17	0.03	0.12	0.20	0.69	0.00

Minimum Correlation Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.18	0.03	0.14	0.22	0.12	0.00
Oil	0.21	0.04	0.14	0.26	-0.25	0.00
Heating oil	0.21	0.02	0.15	0.23	0.42	0.00
Diesel	0.40	0.03	0.36	0.44	0.56	0.00

Minimum Connectedness Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.17	0.03	0.11	0.21	0.13	0.00
Oil	0.23	0.03	0.19	0.28	-0.23	0.00
Heating oil	0.20	0.02	0.15	0.22	0.43	0.00
Diesel	0.39	0.03	0.34	0.44	0.57	0.00

Notes: Table A6 presents the multivariate portfolio allocations for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) from February 25, 2022, until March 28, 2024, across three different portfolio strategies: Minimum Variance Portfolio, Minimum Correlation Portfolio, and Minimum Connectedness Portfolio.

Table A7 Multivariate portfolio

whole time period

Minimum Variance Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.11	0.13	0.00	0.36	0.48	0.00
Oil	0.29	0.25	0.00	0.71	0.30	0.00
Heating oil	0.10	0.17	0.00	0.51	0.40	0.00
Diesel	0.50	0.18	0.19	0.79	0.33	0.00

Minimum Correlation Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.35	0.06	0.23	0.44	0.39	0.00
Oil	0.16	0.08	0.01	0.28	0.17	0.00
Heating oil	0.10	0.10	0.00	0.28	0.29	0.00
Diesel	0.39	0.06	0.27	0.45	0.21	0.00

Minimum Connectedness Portfolio

	Mean	Std. Dev.	5%	95%	HE	p-value
Gasoline	0.36	0.06	0.23	0.46	0.38	0.00
Oil	0.16	0.09	0.00	0.29	0.16	0.00
Heating oil	0.10	0.11	0.00	0.30	0.29	0.00
Diesel	0.39	0.06	0.26	0.46	0.20	0.00

Notes: Table A7 presents the multivariate portfolio allocations for energy-based commodities (Gasoline, Oil, Heating Oil, and Diesel) for whole period, e.g., from January 2, 1998, until March 28, 2024, across three different portfolio strategies: Minimum Variance Portfolio, Minimum Correlation Portfolio, and Minimum Connectedness Portfolio.

Table A8 Summary Statistics of Regression Variables

	Obs.	Mean	Std. Dev.	Min	25 %	50 %	75 %	Max
ΔInterest rate	250	0.04	1.58	-4.17	-0.27	0.03	0.88	4.33
Solvency	234	12.05	3.50	5.40	8.50	12.62	14.74	19.40
ΔCPI	250	0.10	1.61	-3.16	-0.63	-0.06	0.51	5.55
NPL	207	2.63	5.92	0.05	0.76	1.47	2.56	63.04
Δ Tier 1 capital ratio	141	0.00	0.01	-0.02	0.00	0.00	0.00	0.02
GDP Growth	260	2.07	2.00	-4.10	1.70	2.30	3.10	6.20
ΔUncertainty (EPU)	250	7.92	46.05	-76.59	-26.29	6.50	33.92	119.69
REER	260	94.19	8.22	80.50	87.77	95.09	101.02	107.44
Geopolitical risk	217	0.27	0.31	0.02	0.10	0.17	0.31	1.78
Credit risks	217	101.52	38.00	59.02	80.11	91.70	113.02	403.71
Economic condition	217	7.55	0.46	6.60	7.17	7.53	7.91	8.47
Monetary condition	217	2.18	1.27	0.21	1.31	1.82	2.85	5.10

Notes: Table A8 reports summary statistics for the variables employed in the regression analyses presented in Table 6 and Table 7. Δ denotes first differences. In this case, REER (Real Effective Exchange Rate) specifically refers to the U.S. dollar. It serves as an indicator of the United States' international price competitiveness by capturing both nominal exchange rate movements and differences in inflation between the U.S. and its trading partners.

Table A9 Correlation Matrix of Regression Variables (Table 6)

	Geopolitical risk	Credit risks	Economic conditions	Monetary conditions
Geopolitical risk	1.00			
Credit risks	-0.12	1.00		
Economic conditions	-0.30	0.52	1.00	
Monetary conditions	0.36	0.01	-0.24	1.00

Notes: Table A9 presents pairwise Pearson correlation coefficients among key explanatory variables employed in Table 6 regressions.

Table A10 Correlation Matrix of Regression Variables (Table 7)

	Δ Interest rate	Solvency	Δ CPI	NPL	Δ Capital	GDP Growth	Δ Uncertainty (EPU)	REER
Δ Interest rate	1.00							
Solvency	0.19	1.00						
Δ CPI	0.36	0.14	1.00					
NPL	-0.04	0.11	-0.11	1.00				
Δ Tier 1 capital ratio	0.09	-0.07	-0.06	0.33	1.00			
GDP Growth	-0.36	-0.13	0.50	-0.15	0.20	1.00		
Δ Uncertainty (EPU)	-0.11	0.08	0.18	-0.05	-0.06	0.02	1.00	
REER	0.14	0.06	0.18	-0.24	-0.24	0.22	0.16	1.00

Notes: Table A10 presents pairwise Pearson correlation coefficients among key explanatory variables employed in Table 7 regressions. In this case, REER (Real Effective Exchange Rate) specifically refers to the U.S. dollar. It serves as an indicator of the United States' international price competitiveness by capturing both nominal exchange rate movements and differences in inflation between the U.S. and its trading partners.

Table A11 Augmented Dickey-Fuller (ADF) Test Results for Regression Variables

Variable	ADF Statistic	p-value	Stationarity of series used for estimation	Transformation of primary data
Δ Interest rate	-16.67	0.00	Yes	First difference
Solvency	-5.71	0.00	Yes	None (level)
Δ CPI	-6.94	0.00	Yes	First difference
NPL	-6.45	0.00	Yes	None (level)
Δ Tier 1 capital ratio	-6.27	0.00	Yes	First difference
GDP Growth	-7.36	0.00	Yes	None (level)
Δ Uncertainty (EPU)	-5.60	0.00	Yes	First difference
REER	-11.62	0.00	Yes	None (level)
Geopolitical risk	-5.93	0.00	Yes	None (level)

Notes: Table A11 presents the outcomes of Augmented Dickey-Fuller (ADF) unit root tests applied to regression variables. Where non-stationarity in levels was detected, first differencing was employed; otherwise, variables are used in levels. In this case, REER (Real Effective Exchange Rate) specifically refers to the U.S. dollar. It serves as an indicator of the United States' international price competitiveness by capturing both nominal exchange rate movements and differences in inflation between the U.S. and its trading partners.