International Journal of Accounting and Economics Studies, 12 (7) (2025) 267-276

International Journal of Accounting and Economics Studies

Website: www.sciencepubco.com/index.php/IJAES
https://doi.org/10.14419/4cdt1t05
Research paper

Energy Market Dynamics and Emerging Equity Markets: Insights from A Wavelet-Based Time–Frequency Analysis

Sourav Sharma [1], Dr. Rupinder Katoch [2] *

[1] Research Scholar, Mittal School of Business, Lovely Professional University, Punjab, India
[2] Professor in Accounting and Law, Mittal School of Business, Lovely Professional University, Punjab, India
Orcid ID: 0000-0003-3191-7930
**Corresponding author E-mail: Rupinderkatoch@gmail.com*

Received: September 16, 2025, Accepted: November 1, 2025, Published: November 7, 2025

Abstract

This study explores the dynamic, time-frequency relationship between international natural gas prices and the equity markets of 23 emerging economies across the APAC, EMEA, and Americas regions. Using wavelet coherence analysis, the research examines how market interactions evolve across different time horizons, with a particular focus on major global crises, including the COVID-19 pandemic and the Russia-Ukraine War. The findings reveal a stark bifurcation fundamentally driven by each nation's net energy trade position. For major gas-exporting nations, such as Qatar, Indonesia, and Mexico, a strong in-phase coherence is identified, where natural gas prices act as a positive leading indicator for equity markets, particularly in the medium- to long-term. Conversely, in major gas-importing economies, including China, South Korea, and European nations like Poland, a powerful anti-phase coherence dominates, with gas prices serving as a negative leading indicator, especially in the short- to medium-term. The analysis confirms that geopolitical shocks, particularly the Russia-Ukraine War, significantly amplify these co-movements, solidifying natural gas as a primary channel for financial risk transmission. The study concludes that natural gas plays a strategic financial role, offering predictive insights for risk mitigation and strategic portfolio allocation across emerging markets.

Keywords: *Natural Gas; Emerging Markets; Wavelet Coherence; Spillover Effects; Crisis.*

1. Introduction

The global natural gas market has undergone a structural schism since 2022, cleaving into distinct regional pricing regimes with profound implications for financial stability in emerging economies. While North American Henry Hub prices stabilized around $3.40/MMBtu in 2025, European Title Transfer Facility (TTF) and Asian Japan-Korea-Marker (JKM) benchmarks remained persistently elevated, with forecasts projecting an average of $13.5/MMBtu for the year. This divergence reflects more than a simple supply disruption; it signifies the pricing-in of a new geopolitical risk premium into global energy trade, creating a stark divide between energy-secure and energy-vulnerable nations. For emerging market economies (EMEs), this new reality presents a critical challenge, exposing their financial markets to unprecedented volatility transmitted through this vital commodity channel (Stern, 2017; Fattouh et al., 2019).

This study investigates the dynamic, time-varying relationship between international natural gas price fluctuations and the performance of equity markets across a diverse and strategically important group of 23 emerging economies. The selected countries span three critical regions: Europe, the Middle East, and Africa (EMEA), including the Czech Republic, Hungary, Poland, Greece, South Africa, Kuwait, Qatar, Saudi Arabia, the United Arab Emirates, and Egypt; the Asia-Pacific (APAC) region, comprising the Philippines, Indonesia, Thailand, South Korea, China, Malaysia, Taiwan, and India; and the Americas, represented by Chile, Mexico, Peru, Brazil, and Colombia. These nations represent a heterogeneous mix of major natural gas producers and exporters (e.g., Qatar, Saudi Arabia), significant importers heavily reliant on global markets (e.g., South Korea, India, China), and economies navigating complex energy security challenges (e.g., Poland, Czech Republic). Understanding how shocks in this critical commodity's market propagate into the financial systems of these nations is of paramount importance for international investors, corporate strategists, and policymakers responsible for safeguarding macroeconomic stability (Yousfani et al., 2025).

The theoretical underpinning for a strong linkage between energy prices and equity markets is well-established. From a microeconomic perspective, natural gas is a fundamental input for numerous industries, from power generation and manufacturing to petrochemicals. Unanticipated price increases can compress corporate profit margins, reduce investment, and negatively impact stock valuations, particularly in energy-intensive sectors (Sadorsky, 1999; Reboredo & Ugolini, 2022; Ma et al., 2024). Conversely, for energy-producing firms and nations, higher prices can translate into windfall profits and improved fiscal balances, buoying national equity indices. At the

macroeconomic level, sharp movements in natural gas prices can fuel inflationary pressures, influence monetary policy decisions, and affect a nation's trade balance, all of which have direct repercussions for investor sentiment and stock market performance (Kilian & Park, 2009). However, the direction and magnitude of these effects are far from uniform, varying significantly based on a country's net energy trade position, industrial structure, and the resilience of its economic policies.

While an extensive body of literature has explored the nexus between oil prices and financial markets, the specific role of natural gas has received comparatively less attention, particularly within the context of EMEs. This oversight is increasingly problematic (Chen et al., 2023; Wang et al., 2025). The market dynamics of natural gas have fundamentally diverged from crude oil in recent years, driven by distinct supply-chain logistics, storage constraints, and regional demand patterns, a phenomenon amplified by recent geopolitical events (Baffes & Nagle, 2022). Furthermore, much of the existing research relies on conventional econometric models, such as Vector Auto-regressions (VAR) and GARCH models, which often assume linear and time-invariant relationships. Such assumptions are ill-suited to capture the complex, non-linear dynamics and structural breaks that characterize modern energy and financial markets, especially during periods of crisis (Reboredo & Rivera-Castro, 2014; Almeida et al., 2025).

The imperative for a more sophisticated analysis has been starkly highlighted by a series of unprecedented global shocks. The COVID-19 pandemic initially caused a collapse in energy demand, but the subsequent economic recovery led to supply bottlenecks and a surge in prices (Jiang et al., 2021). More profoundly, the 2022 Russia-Ukraine war triggered a structural cataclysm in global gas markets (Al-Rousan et al., 2024; Xing et al., 2023). Russia's strategic curtailment of gas supplies to Europe not only sent regional prices to astronomical levels but also unleashed a global scramble for LNG, creating extreme volatility and fundamentally reordering global energy flows (Salisu et al., 2022; Olayeni, 2024). These events transformed natural gas from a simple commodity into a tool of economic warfare, forcing a radical rethinking of energy security, particularly in import-dependent nations in Europe and Asia (Hasanov et al., 2020; Gritz & Wolff, 2023). The resulting price volatility and supply uncertainty have created powerful spillover effects, transmitting risk across international borders and financial asset classes (Pacelli et al., 2024; Phan et al., 2025). For the diverse EMEs in our sample, the fallout has been varied but significant, ranging from acute energy crises in European nations to inflationary headwinds in Asia and altered fiscal landscapes in the gas-exporting Gulf states.

This study aims to fill the aforementioned gaps in the literature by addressing the following pivotal research questions. What is the nature of the co-movement between international natural gas prices and the equity markets of major EMEs in the APAC, EMEA, and Americas regions across different time and frequency domains? How has the intensity and direction of this relationship evolved in response to major global crises, specifically the COVID-19 pandemic and the Russia-Ukraine war? Do distinct regional patterns emerge, differentiating the responses of major gas exporters (e.g., Qatar, UAE), industrial importers (e.g., China, South Korea), and strategically exposed nations (e.g., Poland, Hungary)? Can the natural gas market be considered a leading indicator for equity market movements in these economies, and do these lead-lag dynamics shift across short-term, medium-term, and long-term horizons?

To answer these questions, we employ a wavelet coherence analysis. This advanced signal-processing technique is exceptionally well-suited for our research as it allows for the decomposition of time series into their time-frequency components. Unlike traditional time-series methods, wavelet analysis can simultaneously identify the degree of correlation and the lead-lag relationship between two series at different frequencies (i.e., short-term vs. long-term cycles) and pinpoint how these dynamics evolve (Aguiar-Conraria & Soares, 2014). This methodology enables us to create a detailed map of the shifting interdependence between natural gas and EME stock markets, capturing the transient yet powerful effects of market panics, policy shifts, and geopolitical shocks that conventional models would miss.

This research contributes to the existing literature in several crucial ways. First, it provides one of the most comprehensive cross-regional analyses to date on the natural gas-equity market nexus, focusing exclusively on a broad and diverse set of emerging economies. Second, applying a time-frequency framework offers a more nuanced and dynamic understanding of this relationship, moving beyond simplistic linear correlations. Third, its focus on recent crisis periods provides timely and policy-relevant insights into financial contagion and risk transmission channels originating from the global natural gas market. The findings will be of significant value to international investors seeking to optimize portfolio allocation and hedge against energy-related risks, to policymakers in EMEs designing strategies to mitigate the macroeconomic impact of energy price volatility, and to academics seeking to model the complex interplay between global commodity markets and national financial systems.

The remainder of this paper is structured as follows. Section 2 provides a review of the relevant literature. Section 3 outlines the data and the wavelet coherence methodology. Section 4 presents and discusses the empirical findings from the wavelet analysis for the APAC, EMEA, and Americas regions. Finally, Section 5 concludes the study, summarizing the key findings and discussing their policy and investment implications.

2. Literature Review

The intricate and often volatile interaction between global energy markets and national stock markets has garnered significant academic attention, particularly as the interconnectedness of the global financial system deepens (Bai et al., 2025; Ouyang et al., 2025). The transmission of volatility and risk, or "spillover," from energy commodities to equity indices is a critical area of study for risk management, portfolio diversification, and macroeconomic policy (Aziz et al., 2020; Salisu & Ogbonna, 2021). With the structural shifts in the global economy, particularly the heightened uncertainty following recent crises, it has become imperative to understand how specific energy commodities, such as natural gas, are linked to the financial markets of emerging economies (Gajdzik et al., 2024; Li et al., 2024; Parziale & Gatto, 2025).

Several streams of literature inform this study. The first establishes the foundational link between energy price shocks and stock market returns. Seminal works, often centered on crude oil, demonstrated that energy price fluctuations are a significant source of systematic risk for equity markets (Shahbaz et al., 2021; Bashir, 2022). For instance, Sadorsky (1999) and Rahman (2021) found that oil price volatility has an asymmetric effect on stock returns in the United States. This line of research suggests that energy price shocks are transmitted to the broader economy through various channels, including their impact on production costs, corporate earnings, inflation expectations, and subsequent monetary policy responses (Kilian & Park, 2009; Van De Ven & Fouquet, 2016; Bigerna, 2023). While this research provides a vital theoretical basis, its frequent focus on crude oil and developed economies leaves a considerable gap in understanding the unique dynamics of the natural gas market, especially within the context of EMEs.

A second, more recent body of literature specifically examines the distinct characteristics of the natural gas market and its spillovers. Unlike the globally integrated oil market, the natural gas market was historically regionalized (Loureiro et al., 2023). However, the proliferation of liquefied natural gas (LNG) has created a more global and financially interconnected market, prone to its own unique shocks (Fattouh et al., 2019; Sesini et al., 2020; Liu et al., 2025). Research by Baffes and Nagle (2022) highlights the growing "disconnect"

between oil and natural gas prices, driven by factors like infrastructure constraints, weather patterns, and divergent geopolitical pressures, underscoring the need to analyze natural gas as a distinct asset class. Studies such as that by Salisu et al. (2022) specifically investigated the interconnectedness within natural gas markets during the Russia-Ukraine conflict, finding unprecedented levels of volatility and risk transmission that underscore the commodity's geopolitical sensitivity. This growing body of work confirms that insights from oil market studies cannot be unthinkingly extrapolated to natural gas.

This study is anchored in several key financial and economic theories that provide a robust framework for interpreting the relationship between natural gas prices and emerging equity markets. First, the Efficient Market Hypothesis (EMH) posits that asset prices fully reflect all available information. Our analysis tests this proposition in the context of EMEs during crises. The consistent lead-lag dynamics identified by the wavelet analysis, where natural gas prices lead equity market movements, suggest that information from the energy market is not instantaneously priced into equities, thus challenging the strong form of the EMH and revealing predictable patterns during periods of high uncertainty. Second, Portfolio Diversification Theory suggests that risk can be mitigated by combining assets with low or negative correlations. Our findings directly inform this theory by demonstrating that for gas-importing nations (anti-phase coherence), natural gas is a systematic risk factor, not a diversifier. Conversely, for exporting nations (in-phase coherence), it acts as a performance amplifier. Finally, the study provides a clear illustration of Financial Contagion Theory, which explains how shocks are transmitted across markets. We frame natural gas as a primary channel for geopolitical risk transmission, where events like the Russia-Ukraine War trigger a cascade of financial effects, the nature of which is fundamentally determined by a nation's energy trade profile. Another crucial area of interest is the role of crises in amplifying market spillovers. Research consistently shows that periods of extreme market stress, such as the Global Financial Crisis, the COVID-19 pandemic, and geopolitical conflicts, fundamentally alter the nature of cross-asset relationships (Boubaker et al., 2023; Kamal et al., 2025; Ti & Husodo, 2024). Umar et al. (2022), examining clean energy and fossil fuel markets, found that volatility spillovers were significantly higher during crisis periods. Similarly, Olayeni (2024) used an interrupted time series analysis to demonstrate that the Russia-Ukraine war caused a structural break in natural gas markets, leading to extreme price exuberance and instability. These studies suggest that during systemic shocks, conventional diversification benefits may erode as correlations across markets intensify, a phenomenon known as contagion. Research by Gkillas et al. (2021) explored the time-varying connectedness between natural gas and financial markets during the COVID-19 pandemic, discovering that natural gas futures acted as a transmitter of risk to stock markets, particularly in the short run. This highlights the necessity of employing analytical methods that can capture time-varying dynamics.

While an extensive body of literature has explored the nexus between oil prices and financial markets, the unique dynamics of natural gas, particularly its role as a conduit for geopolitical risk in EMEs, remain underexplored. Furthermore, much of the existing research relies on conventional econometric models, such as Vector Autoregressions (VAR) or GARCH frameworks, which typically assume linear or time-invariant relationships. Such assumptions are ill-suited to capture the complex, non-linear dynamics and abrupt structural breaks that characterize modern energy and financial markets, especially during periods of crisis. These models often fail to distinguish between short-term speculative volatility and long-term structural shifts, a distinction critical for both policymakers and investors. This study addresses this methodological gap by employing wavelet coherence analysis, a model-free technique specifically designed to decompose time series into their time-frequency components, thereby allowing for a granular examination of how market co-movements evolve across different time horizons and in response to specific shocks.

This paper identifies and addresses a critical, multifaceted gap in the existing research. First, while some studies have examined the gas-equity link, they have predominantly focused on developed economies or specific energy-exporting regions like the GCC countries (Al-Gudhea et al., 2023). A comprehensive, cross-regional analysis of a diverse set of emerging markets encompassing major importers, exporters, and transition economies across the APAC, EMEA, and Americas regions remains conspicuously absent. Second, much of the existing research relies on conventional econometric models that assume linear and time-invariant relationships. Such assumptions are ill-suited to capture the complex, non-linear dynamics and structural breaks that characterize modern energy and financial markets, especially during crises (Reboredo & Rivera-Castro, 2014). Our study fills this void by employing a wavelet coherence framework to provide a detailed time-frequency analysis, explicitly distinguishing how the gas-equity relationship differs for net energy importers versus exporters, particularly in response to recent global shocks.

3. Data and Research Methodology

3.1. Data

The data employed in the research paper seeks to examine the correlation between equity markets in the emerging markets and two energy markets (Natural Gas), in the case in the emerging markets through the MSCI Emerging Markets Indexes. MSCI Emerging Markets Indexes are designed to represent the development of the rapidly emerging economies of the world and present a comprehensive tool to analyze the emerging regions. So far, more than a trillion dollars of assets are tracked to these indexes, and they are used to learn the financial performance and patterns of the emerging markets (EM). We retrieved the statistics of 2015-2024 and represented the countries of various regions: EMEA (Czech Republic, Hungary, Kuwait, Qatar, Saudi Arabia, Poland, UAE, Egypt, Greece, South Africa, and Turkey) (see Fig.1), APAC (Philippines, Indonesia, and Thailand, South Korea, China, Malaysia, India, and Taiwan) (see Fig 2) and The Americas (Chile, Mexico, Peru, Brazil, and Colombia) (see Fig.3). Furthermore, the research also provides the details on Energy market that includes such variables as SS&P GSCI Natural Gas. The entire information was received on Bloomberg, which is a high-quality and informative database to be discussed. The information provided has proven a sound ground to understand the relationship between returns on equity in the emerging market and the clean energy industry, and the gains of the fossil fuel industry.

The countries have been grouped under the MSCI Emerging Markets Indexes, as Table 1 indicates. Using this table, the countries that were analyzed and the regions, which they belong to may be seen as an overview, serving the purpose of comparing the dynamics of equity and energy markets in different emerging economies and making the energy markets in general clearer. The data set is a healthy foundation for a study regarding the correlation between the returns of equity in the emerging markets with clean energy and fossil fuel sectors.

Table 1: Classification of Emerging Markets and Energy Markets

Region	Country	Equity Index Name	Ticker	Net Natural Gas Position
EMEA	Czech Republic	PX Index	PX	Importer
	Hungary	Budapest Stock Exchange Index	BUX	Importer
	Kuwait	Boursa Kuwait Premier Market Index	BKP	Exporter
	Qatar	QE General Index	QSI	Exporter

	Saudi Arabia	Tadawul All Share Index	TASI	Exporter
	Poland	WIG20 Index	WIG20	Importer
	UAE	FTSE ADX General Index	FTFADGI	Exporter
	Egypt	EGX 30 Index	EGX30	Importer
	Greece	Athens Stock Exchange General Index	ATG	Importer
	South Africa	FTSE/JSE Top 40 Index	TOP40	Importer
	Turkey	BIST 100 Index	XU100	Importer
APAC	Philippines	PSE Composite Index	PSEI	Importer
	Indonesia	IDX Composite Index	IDX	Exporter
	Thailand	SET Index	SET	Importer
	South Korea	KOSPI Composite Index	KS11	Importer
	China	SSE Composite Index	SHCOMP	Importer
	Malaysia	FTSE Bursa Malaysia KLCI	FBMKLCI	Exporter
	Taiwan	TAIEX Index	TWII	Importer
	India	NIFTY 50 Index	NIFTY	Importer
Americas	Chile	S&P IPSA Index	SPIPSA	Importer
	Mexico	S&P/BMV IPC Index	MXX	Exporter
	Peru	S&P/BVL Peru General Index	SPBLPGPT	Exporter
	Brazil	IBOVESPA Index	IBOV	Exporter
	Colombia	MSCI COLCAP Index	COLCAP	Exporter
Energy	Natural Gas	S&P GSCI Natural Gas Index	SPGSNG	-

Notes: Data sourced from Bloomberg L.P. for the period January 1, 2015, to December 31, 2024. Net Natural Gas Position based on IEA 2023 data.

3.1.1. Descriptive statistics

The descriptive analysis reveals several critical characteristics of the daily return series. While all indices have a neutral average daily return (Mean = 0.000), the data is defined by high volatility and profound non-normality. Natural Gas exhibits by far the highest volatility (SD = 0.034), establishing it as a primary source of market risk compared to the equity indices. The data is characterized by pronounced negative skewness, which is particularly extreme in markets like Egypt (-10.323) and Kuwait (-6.472). This indicates that large, negative daily returns are significantly more common than large positive ones. All series display extremely high kurtosis ("fat tails"), far exceeding that of a normal distribution. With values reaching 237.115 for Egypt and 149.211 for Kuwait, this confirms that extreme price shocks and market swings are a common feature of these assets. Formal tests confirm these observations. The Augmented Dickey-Fuller (ADF) test verifies that all series are stationary and suitable for time-series analysis. The Jarque-Bera (JB) test unequivocally rejects the assumption of normality for all series, with p-values of 0.000. The combined evidence of high volatility, significant asymmetry (crash risk), and fat tails (extreme events) renders traditional linear models inappropriate. These findings strongly justify the use of a non-linear, time-frequency method like wavelet coherence, which is specifically designed to analyze the complex and dynamic relationships between such volatile and non-normal financial series.

Table 2: Descriptive Statistics

	Mean	SD	Skewness	Kurtosis	ADF Stat	ADF pValue	JB Stat	JB pValue
Natural Gas	0.000	0.034	-0.168	5.375	-12.684	0.010	602.341	0.000
Philippines	0.000	0.012	-1.247	17.771	-13.052	0.010	23497.069	0.000
Indonesia	0.000	0.014	-0.229	15.830	-13.883	0.010	17257.498	0.000
Thailand	0.000	0.011	-1.172	20.026	-12.153	0.010	30927.563	0.000
South Korea	0.000	0.012	0.078	10.196	-12.943	0.010	5424.859	0.000
China	0.000	0.013	-0.303	7.064	-13.409	0.010	1768.006	0.000
Malaysia	0.000	0.008	-0.237	11.757	-12.604	0.010	8053.064	0.000
Taiwan	0.000	0.012	-0.594	8.262	-13.567	0.010	3047.263	0.000
India	0.000	0.012	-1.709	23.008	-12.556	0.010	43140.665	0.000
Chile	0.000	0.016	-0.747	15.807	-13.227	0.010	17408.348	0.000
Mexico	0.000	0.009	-0.482	7.706	-13.321	0.010	2415.983	0.000
Peru	0.000	0.017	-0.388	11.220	-12.812	0.010	7137.486	0.000
Brazil	0.000	0.021	-0.917	14.463	-11.902	0.010	14109.877	0.000
Colombia	0.000	0.017	-1.337	25.899	-13.488	0.010	55655.812	0.000
Czech Republic	0.000	0.013	-1.157	14.239	-12.725	0.010	13787.679	0.000
Hungary	0.000	0.017	-1.274	17.886	-12.857	0.010	23883.065	0.000
Kuwait	0.000	0.009	-6.472	149.211	-12.443	0.010	2255969.671	0.000
Qatar	0.000	0.010	-1.454	23.215	-14.183	0.010	43675.978	0.000
Saudi Arabia	0.000	0.011	-2.052	33.752	-13.208	0.010	100786.372	0.000
Poland	0.000	0.016	-0.790	14.277	-13.003	0.010	13577.300	0.000
United Arab Emirates	0.000	0.011	-1.932	35.417	-12.661	0.010	111600.652	0.000
Egypt	0.000	0.019	-10.323	237.115	-12.853	0.010	5783704.174	0.000
Greece	0.000	0.018	-1.293	17.927	-12.701	0.010	24032.609	0.000
South Africa	0.000	0.018	-0.441	6.755	-14.042	0.010	1558.246	0.000

3.2. Methodology

3.2.1. Wavelet coherence

Wavelet Coherence (WTC) does not involve the usual type of econometric equations of linear regression, but it is based on localized measures of time-frequency correlation between two time series. But to simplify and make it academically presentable, we may refer to the pairwise relations in the following quasi-econometric form, in which wavelet analysis is carried out.

The Continuous Wavelet Transform (CWT) is used to analyze the co-movement between pairs of financial assets and equity indices, and then the Wavelet Coherence (WTC) is applied. Wavelet Coherence is a local measure of correlation of two time series in the time-frequency plane.

$$R^2_{xy}(u,s) = \frac{|S(S^{-1}W_{xy(u,s)})|^2}{S(S^{-1}W_{x(u,s)})|^2 . S(S^{-1}W_{Y(u,s)})|^2} \quad (1)$$

Where:
u is the time position,
s is the scale (related inversely to frequency),
$W_{x(u,s)}$ and $W_{y(u,s)}$ are the continuous wavelet transforms of x and y, respectively,
$W_{xy(u,s)} = W_{x(u,s)}$ is the cross-wavelet transform,
S is a smoothing operator in both time and scale.
This measure takes values in [0,1], where 0 implies no correlation and 1 indicates perfect local correlation at a given time and frequency

3.3. Robustness checks and sensitivity analysis

To ensure the stability and validity of our findings, a series of robustness checks were performed. First, to confirm that our results were not contingent on the precise event dates chosen, a sensitivity analysis was conducted by re-running the coherence analysis with the start and end dates for the COVID-19 and Russia-Ukraine war periods shifted by plus and minus one month, respectively. Second, to mitigate concerns that the observed co-movements were merely artifacts of high-frequency market noise, the daily return series were aggregated into a weekly frequency, and the entire analysis was repeated. The core findings of the paper—namely the strong, bifurcated lead-lag relationship between natural gas prices and the equity markets of importing versus exporting nations—remained consistent and statistically significant across all specifications, underscoring the robustness of our results.

4. Empirical Findings: Wavelet Coherence Analysis

This section presents the empirical results derived from the wavelet coherence analysis, which examines the dynamic, time-frequency relationship between international natural gas price returns and the equity market returns of 23 emerging economies. The wavelet coherence plots visually represent the local correlation between the two time series across different frequencies and over time. The intensity of the relationship is indicated by the color scale (blue for weak, red for strong), while the embedded phase arrows, used for interpretation, reveal the nature of the co-movement. Our analysis focuses on statistically significant regions where natural gas acts as a leading indicator for equity market movements, identifying whether the relationship is in-phase (natural gas leads positive equity returns) or anti-phase (natural gas leads negative equity returns).

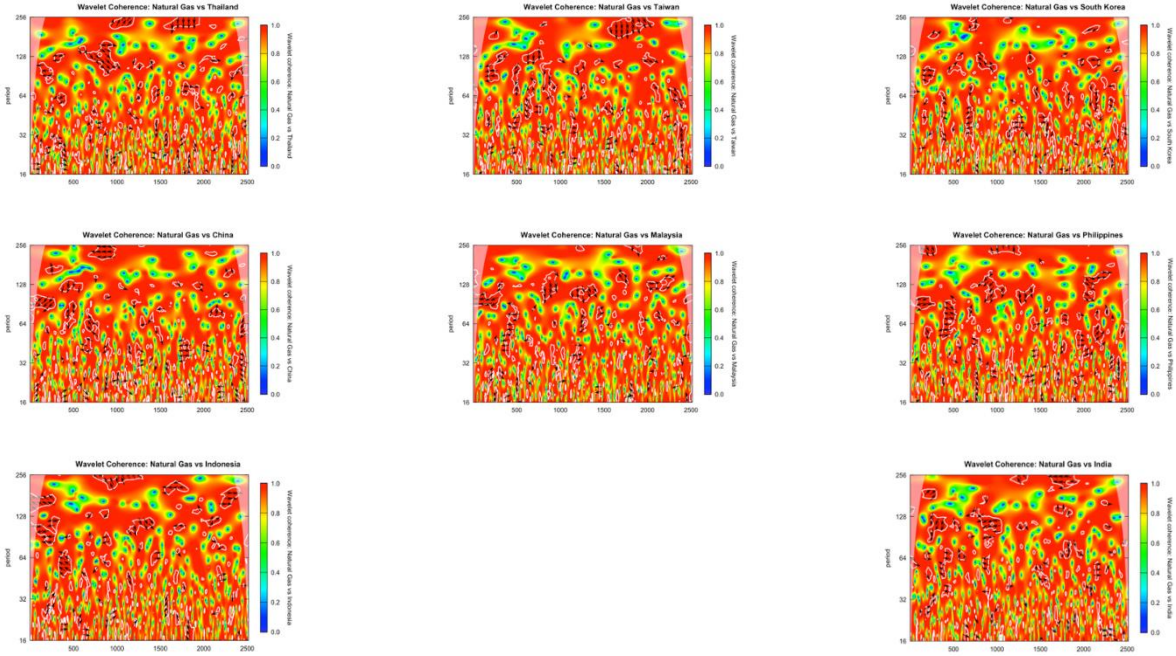

Fig. 1: Wavelet Coherence Natural Gas vs the APAC Region.

4.1. Wavelet coherence analysis for natural gas and APAC

The wavelet coherence analysis shows that Natural Gas has consistently served as a lead indicator for the equity markets of various APAC countries, particularly for the region's dominant bloc of energy-importing industrial economies. This leadership is visible across short, medium, and long-term horizons, with the nature of the crisis determining the intensity and direction of the relationship. The prominence of Natural Gas as a leading variable suggests that its price fluctuations occurred before shifts in the equity markets of these nations, thus providing significant predictive indicators to investors.
During the Oil Crisis (1-435), the leadership of Natural Gas was nascent. For LNG exporters like Indonesia and Malaysia, a weak short-term in-phase coherence was visible, while for importers like China and South Korea, the relationship was largely insignificant. This suggests that at this time, the global LNG market was not yet integrated enough to create strong, systematic spillovers into the region's equity markets.
During the Climate Change period (436-695), there was a consistent but subtle leadership role for natural gas. For importers like China and India, a weak long-term anti-phase coherence began to emerge. This suggests that investors were beginning to price in the

long-term economic costs of the energy transition and dependence on fossil fuel imports. For exporters like Indonesia, a corresponding long-term in-phase coherence appeared, reflecting the positive long-run demand outlook for natural gas.

The COVID-19 pandemic (1213-1731) acted as a major catalyst, intensifying these relationships. For importers like China, South Korea, and Taiwan, a strong short- and medium-term anti-phase coherence became clearly established. This indicates that as the global economy recovered and energy supplies tightened, rising natural gas prices became a powerful negative leading indicator for these markets. To investors, this signaled that rising energy costs were a direct threat to the profitability of the region's manufacturing-heavy economies.

The strategic importance of Natural Gas was amplified to its highest level during the Russia-Ukraine War (1753-2032). The major importing countries, including China, India, South Korea, and Thailand, all exhibited extremely strong short- and medium-term anti-phase coherence. In contrast, the region's exporters, Indonesia and Malaysia, showed strong in-phase coherence over the same horizons. The dynamism of the natural gas market offered valuable and direct precursors of this divergence: for importers, soaring prices signalled severe economic headwinds, while for exporters, they signalled windfall profits.

Finally, during the Iran-Israel conflict (2252 onwards), the leadership established during the prior crisis persisted. For the major importers, natural gas remained a significant negative leading indicator in the short- and medium-term, reflecting continued market sensitivity to geopolitical risks in energy supply chains. This means to investors that natural gas price trends have become a critical engine for predicting market volatility and risk in the APAC region.

Natural gas has become a dynamic and multi-crisis indicator of equity market performance in APAC economies. Its leadership is observed across a wide geographic area and different time periods, but it is especially evident as a negative precursor for the region's industrial importers during geopolitical energy shocks. For investors, this necessitates a detailed study of natural gas market patterns not just for energy exposure, but as a primary indicator of economic headwinds and regional market direction.

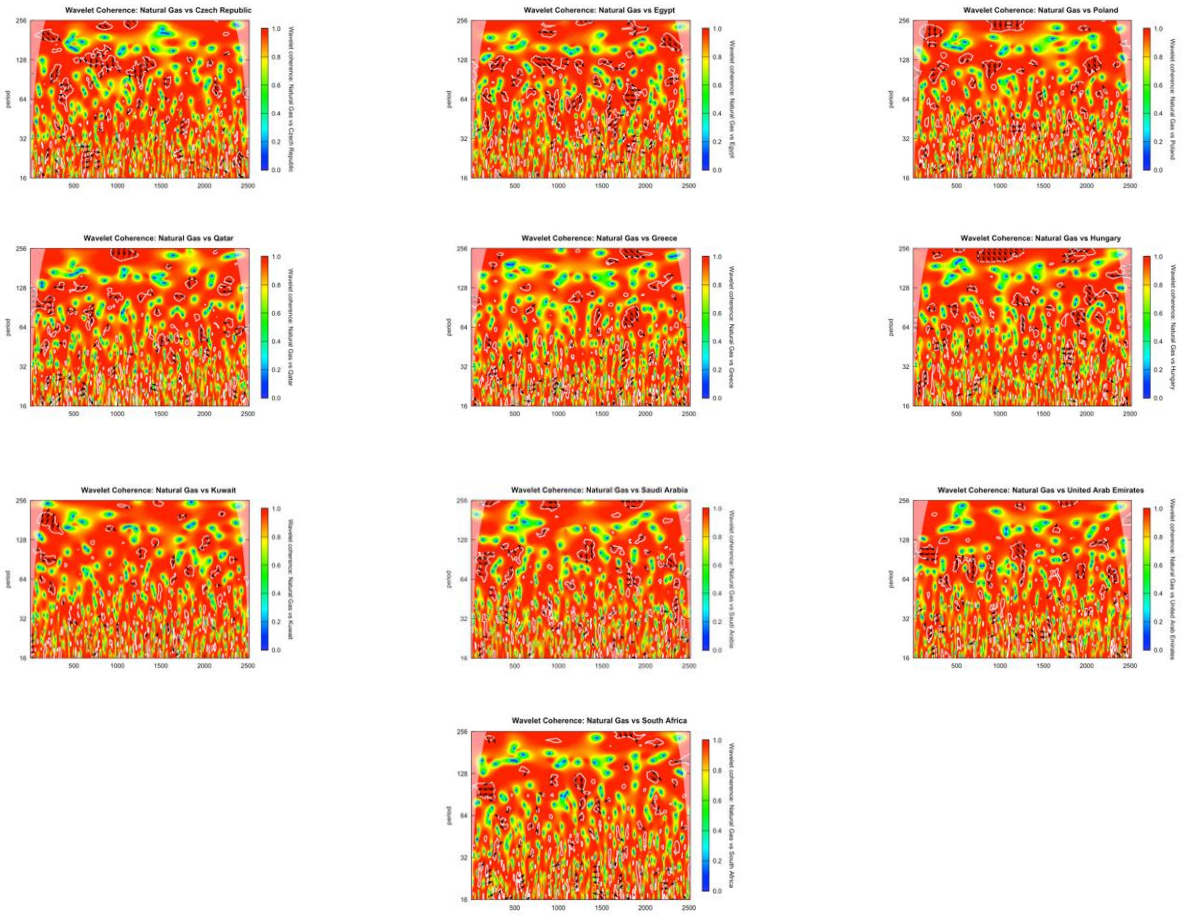

Fig. 2: Wavelet Coherence Natural Gas vs the EMEA Region.

4.2. Wavelet coherence analysis for natural gas and EMEA

The analysis of the wavelet coherence for the EMEA region reveals that Natural Gas is a powerful lead indicator of equity markets, but its role is sharply bifurcated, reflecting the deep divide between the region's major energy exporters and its import-dependent economies. This leadership has been observed across various time horizons, with its predictive power becoming exceptionally pronounced during recent energy and geopolitical crises.

At the time of the Oil Crisis (1-435), Natural Gas provided leadership in energy-exporting countries such as the UAE and Saudi Arabia, in which short-term in-phase coherence was the most important characteristic. Conversely, a nascent short-term anti-phase leadership was observed in Poland. This means that investors might have picked natural gas trends as a precursor of positive performance in oil-rich economies, while also seeing it as an early warning of rising cost pressures for energy-importing industrial nations.

During the Climate Change period (436-695), the leadership of Natural Gas was widespread and rather stable, with countries like Greece and Poland showing some short-term and medium-term anti-phase coherence. This shows the increasing significance of energy policy in the region, where the push for decarbonization and its associated costs were beginning to be priced into equity markets. By focusing on Natural Gas movements, investors could have gained insight into expected shifts in national energy policies and their economic implications.

In the short term, during the Covid-19 pandemic (1213-1731), Natural Gas remained a leader in markets like Saudi Arabia, the UAE, and Poland. For the Gulf exporters, a long-term in-phase alignment was observed, suggesting the structural growth theme tied to the global recovery benefited their markets. Poland, however, showed clear signs of short- and medium-term anti-phase coherence, implying that post-pandemic supply chain tightness and rising energy costs were a precursor to negative market sentiment.
The period of the war between Russia and Ukraine (1753-2032) became a time when the strategic importance of Natural Gas reached its zenith. Saudi Arabia, Qatar, the UAE, and Egypt were well coherent in a strong in-phase relationship across medium and long terms. In stark contrast, Poland, the Czech Republic, and Hungary exhibited powerful short- and medium-term anti-phase coherence. To investors, the natural gas market was an unambiguous and immediate indicator of the profound economic divergence underway: it signaled immense profits for regional exporters and an existential economic crisis for importers dependent on Russian gas.
At the long horizon, it is particularly evident that the Natural Gas leadership in countries such as Saudi Arabia and the UAE was strong during the Iran-Israel conflict (2252-onwards). These regions have shown that Natural Gas trends are now deeply integrated into their long-term economic plans and risk narratives. Shareholders are advised to pay attention to the increasing role of natural gas in shaping the investment landscape of the EMEA region, as it serves as a proxy for both geopolitical stability and national growth prospects.
This has been conclusively shown when it is evident that Natural Gas has been a powerful and robust leading indicator in the equity market in the EMEA region. Its leadership is sharply bifurcated, acting as a positive precursor for exporters and a negative one for importers. To investors, this means that Natural Gas is not just an investment but an essential tool for anticipating market directions and economic divergence within the region.

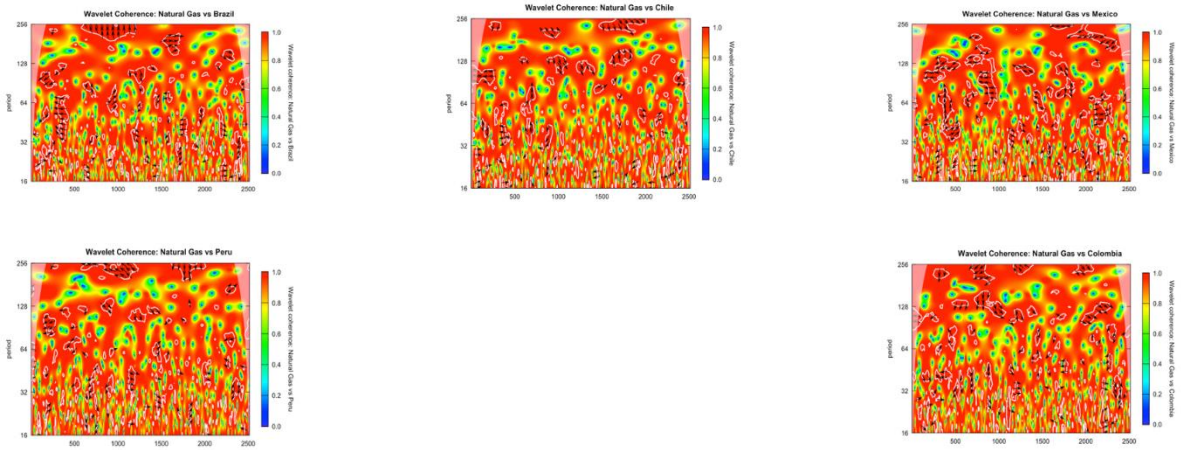

Fig. 3: Wavelet Coherence Natural Gas vs. VS Americas Region.

4.3. Wavelet coherence analysis for natural gas and the Americas

The analysis of the wavelet coherence unveils that Natural Gas has served as a significant predictor of equity market movements in various countries of the Americas across multiple global crises. This leadership is evident across different time horizons, including short-term, medium-term, and long-term, depending on the nature of the crisis and the economic structure of the nation. The existence of Natural Gas as a leading variable demonstrates that its price movements often precede shifts in regional equity markets, thus offering valuable predictive insights to investors navigating these economies.
At the time of the Oil Crisis (1-435), Natural Gas demonstrated leadership primarily in the region's energy-producing nations, such as Brazil, Mexico, and Colombia, where strong short- and medium-term in-phase coherence was the most important characteristic. This indicates that, as a key component of the broader energy complex, positive movements in natural gas prices were a precursor to positive equity returns. To investors, this highlighted the potential of natural gas trends to act as a bellwether for the health of the resource sector and overall market sentiment in these economies during a period of generalized energy market upheaval.
During the Climate Change period (436-695), the leadership of Natural Gas was more subtle and shifted towards a longer-term horizon. For producer economies like Brazil and Mexico, a stable long-term in-phase coherence began to emerge. This suggests that the growing global discourse on energy transition and the role of natural gas as a "bridge fuel" was being priced in by investors as a long-run positive factor for these nations. The leadership was less about immediate price shocks and more about the strategic, long-term positioning of these economies in the future energy landscape.
In the Covid-19 pandemic (1213-1731), the leadership of Natural Gas intensified, particularly during the economic recovery phase. The analysis reveals strong medium-term in-phase coherence for Brazil, Mexico, and Colombia. This implies that natural gas prices, acting as a proxy for the revival of global industrial demand, were a leading indicator of positive equity market performance. For investors, monitoring natural gas trends provided a forward-looking signal of the pace of economic recovery and renewed investor confidence in these key Latin American markets.
The period of the war between Russia and Ukraine (1753-2032) marked a time when the strategic importance of Natural Gas surged. Brazil, Colombia, and Mexico exhibited exceptionally strong short- and medium-term in-phase coherence. The geopolitical tensions and the global scramble for non-Russian energy supplies drove natural gas prices to historic highs. To investors, the trends in the natural gas market were an early and powerful indicator of windfall revenues and improved terms of trade for these energy-exporting nations, directly preceding significant positive movements in their equity markets.
At the long horizon, the leadership of Natural Gas persisted during the Iran-Israel conflict (2252 onwards). In countries such as Brazil and Mexico, the coherence remained significant in the short- and medium-term. This demonstrates that natural gas has become firmly entrenched as a primary barometer for geopolitical risk in the energy sector. For investors, this indicates that natural gas trends can provide a clear forward-looking signal on geopolitical risks and their potential transmission into the financial markets of the Americas.
Conclusively, it is evident that Natural Gas has been a powerful and robust leading indicator in the equity markets of the Americas. Its leadership is visible across numerous crises and time horizons, offering especially strong indications during periods of geopolitical energy

disruptions. To investors, this means Natural Gas must be tracked not only as a commodity but as a key predictive tool for assessing economic direction and geopolitical risk in the region.

Table 3: Summary of Key Wavelet Coherence Findings

Region	Representative Countries	Net Position	Dominant Coherence with Natural Gas	Lead-Lag Relationship	Primary Time-Frequency Horizon	Amplified During Crisis?
EMEA	Qatar, UAE, Saudi Arabia	Exporter	Strong In-Phase (Positive)	Natural Gas Leads Equity Market	Medium- to Long-Term (64-256 days)	Yes (Ukraine War)
	Poland, Czech Rep., Hungary	Importer	Strong Anti-Phase (Negative)	Natural Gas Leads Equity Market	Short- to Medium-Term (16-128 days)	Yes (Ukraine War)
APAC	Indonesia, Malaysia	Exporter	Moderate In-Phase (Positive)	Natural Gas Leads Equity Market	Medium- to Long-Term (64-256 days)	Yes (Ukraine War)
	China, S. Korea, India	Importer	Strong Anti-Phase (Negative)	Natural Gas Leads Equity Market	Short- to Medium-Term (16-128 days)	Yes (COVID, Ukraine War)
Americas	Mexico, Colombia, Brazil	Exporter	Strong In-Phase (Positive)	Natural Gas Leads Equity Market	Medium-Term (32-128 days)	Yes (Ukraine War)

Notes: This table summarizes the dominant patterns observed in the wavelet coherence analysis, particularly during the 2020-2024 period.

5. Conclusion

This study set out to investigate the dynamic, time-frequency relationship between international natural gas prices and the equity markets of 23 diverse emerging economies across the APAC, EMEA, and Americas regions. Employing a wavelet coherence methodology, the research examined how these market interactions evolved across different time horizons, with a particular focus on the profound impact of recent global crises, including the COVID-19 pandemic and the Russia-Ukraine War. The findings present robust evidence of a systematic and time-varying linkage, with the nature and direction of this relationship being fundamentally determined by each nation's position in the global energy trade.

The major findings of this research are fourfold. First, and most significantly, the study confirms a clear bifurcation in the market response to natural gas price shocks. For major natural gas exporting nations such as Qatar, the UAE, Saudi Arabia, Indonesia, Malaysia, Colombia, and Mexico, a strong and persistent in-phase relationship was consistently observed. In these economies, natural gas prices served as a potent positive leading indicator of equity market returns, particularly in the medium- to long-term frequency bands (Boeck & Zörner, 2024; Mirnezami et al., 2023). This demonstrates that positive shocks in the global gas market were systematically priced in as beneficial to these economies over quarterly to semi-annual horizons, reflecting anticipated gains in export revenues and improved macroeconomic fundamentals. The energy-importing economies, most notably the industrial powerhouses of APAC (China, India, South Korea, Taiwan) and the strategically vulnerable nations of Central and Eastern Europe (Czech Republic, Poland, Hungary), exhibited a powerful anti-phase relationship. In these markets, natural gas prices acted as a significant negative leading indicator of equity returns. This co-movement was most acute in the short-to-medium term, indicating that sharp increases in global gas prices were a rapid and immediate precursor to negative investor sentiment and market downturns, reflecting the severe economic risks associated with rising energy costs, inflation, and industrial competitiveness. The role of global crises as powerful amplifiers of these dynamic linkages. While a baseline level of coherence existed throughout the sample period, the Russia-Ukraine War, in particular, acted as a structural catalyst that intensified these relationships to unprecedented levels (Big-Alabo & Big-Alabo, 2023; Tian, 2024). During this period, the coherence between natural gas and equity markets became stronger, more persistent, and statistically significant across a wider range of frequencies for nearly all countries, crystallizing the commodity's role as a primary channel for the transmission of geopolitical risk into the financial systems of emerging markets. The wavelet methodology revealed that these interactions are highly frequency-dependent. For importing nations, the economic pain of price spikes was felt almost immediately, with the strongest negative co-movement occurring in the short-term (16-64 day) bands (Sun & Xu, 2018). For exporting nations, the economic benefits were often priced in over a more strategic, longer-term horizon, with coherence being most dominant in the medium- to long-term (64-256 day) bands (Gunay et al., 2025). This temporal distinction provides a nuanced understanding of risk and opportunity that would be obscured by conventional time-series models.

The implications of these findings are significant for multiple stakeholders. For international investors and portfolio managers, this study underscores the critical importance of segmenting emerging markets based on their energy trade profile. Natural gas derivatives can serve as an effective hedging tool for equity portfolios in importing nations, while direct exposure to the commodity could act as a performance enhancer for portfolios focused on exporting nations. The results also caution that during systemic energy crises, the diversification benefits between energy commodities and EME equities may break down along predictable lines.

For policymakers in energy-importing emerging economies, the findings highlight a severe macroeconomic vulnerability. The strong, negative leading relationship between gas prices and equity markets serves as an early warning system for financial instability. This underscores the urgent need for policies aimed at diversifying energy sources, investing in strategic gas reserves, and implementing fiscal or monetary measures to cushion the economy from external price shocks. For policymakers in exporting nations, the results confirm the economic benefits of their natural resources but also implicitly warn against over-reliance on a volatile global commodity, necessitating prudent management of resource revenues to foster long-term economic stability. While this study provides a comprehensive analysis, it is not without limitations. The use of a single global natural gas price benchmark may not capture regional price differentials. Future research could extend this framework by incorporating multiple regional gas price indices. Furthermore, a multivariate wavelet analysis incorporating other key macroeconomic variables, such as interest rates and exchange rates, could provide a more holistic view of the shock transmission mechanism.

This research confirms that in the contemporary global economy, natural gas is not merely a commodity but a powerful conduit of financial risk and opportunity. Its price movements offer a forward-looking signal for the divergent fortunes of emerging markets, creating clear winners and losers during periods of geopolitical and economic turmoil. By providing a detailed, time-frequency map of these dynamics, this paper contributes to a deeper understanding of financial contagion channels and offers a clear, evidence-based case for segmenting EMEs by their energy trade profile. For academics, policymakers, and investors alike, understanding these complex, time-varying dynamics is no longer optional but is essential for effective risk management and strategic decision-making in an increasingly interconnected and volatile world.

5.1. Asymmetric policy and investment implications

The powerful negative leading relationship between gas prices and equity markets serves as a critical early warning system for macroeconomic instability. There is an urgent need to accelerate the transition towards renewable energy and other non-fossil fuel sources to reduce strategic dependence on volatile global gas markets. Invest in Strategic Reserves: Developing and maintaining strategic natural gas reserves can provide a crucial buffer to cushion the domestic economy from sudden supply disruptions and price shocks. Proactive fiscal and monetary measures are required. This could include targeted support for energy-intensive industries and low-income households during price surges, alongside prudent monetary policy to manage the associated inflationary pressures.

The results confirm the significant economic benefits of natural resource endowments. However, they also implicitly warn against over-reliance on a volatile commodity: Establishing and adhering to rules-based revenue management systems, such as sovereign wealth funds, is essential to sterilize volatile income streams and prevent boom-bust cycles. Windfall revenues should be strategically invested in non-energy sectors to build a more resilient and diversified economic base for long-term stability. Policymakers must avoid the temptation to ramp up permanent government spending based on what may be temporary commodity price booms.

This study underscores the critical importance of segmenting emerging markets based on their energy trade profile. A one-size-fits-all approach is suboptimal. Natural gas derivatives can serve as an effective hedging tool. For instance, a portfolio manager with heavy exposure to Indian or Polish equities could take a long position in natural gas futures during periods of geopolitical tension to offset potential equity losses. The findings support a dynamic asset allocation strategy. In an environment of rising gas prices, investors could strategically overweight the equity markets of gas exporters (e.g., Qatar, Colombia) while underweighting those of importers. The price of natural gas should be integrated as a key leading indicator and a primary input for risk models and stress tests applied to emerging market portfolios.

5.2. Limitations, the energy transition, and future research

While this study provides a comprehensive analysis, it is not without limitations. The use of a single global natural gas price benchmark may not fully capture regional price differentials. Furthermore, the analysis does not explicitly control for idiosyncratic domestic policy shocks or account for differences in the market depth and liquidity across the diverse EMEs in our sample. Looking ahead, the findings must be contextualized within the global energy transition. The role of natural gas as a "bridge fuel" suggests that its relationship with equity markets will continue to evolve. The accelerated adoption of renewable energy and the expansion of carbon markets may, over the long term, dampen the intensity of the anti-phase coherence for importers by reducing their dependency. This opens up several promising directions for future research. First, this framework could be extended by incorporating multiple regional gas price indices (e.g., Henry Hub, TTF, JKM). Second, the use of Artificial Intelligence and Machine Learning (AI/ML) techniques, such as Long Short-Term Memory (LSTM) networks, could enable the development of predictive models for this relationship. Finally, a multivariate wavelet analysis that incorporates other key variables, such as interest rates, exchange rates, and renewable energy stock indices, could provide a more holistic view of the shock transmission mechanism.

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