Economic Researcher Review
ISSN: 2335-1748, EISSN: 2588-235X
VOL 13,N^{O} 2 (Year 2025)
Available online at https://www.asjp.cerist.dz/en/PresentationRevue/85

Price Volatility in European Natural Gas Spot Markets: Impact of the Russia-Ukraine Crisis on Emerging Market Economies

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Received: 08-11-2024 **Accepted:** 11-11-2025 **Published:** 12-30 -2025

Abstract :

This study investigates how the heightened volatility of European natural gas spot markets—intensified by Russia's invasion of Ukraine on February 24, 2022—has affected emerging market economies. Using daily data from January 2020 to December 2024 (1,261 observations) and a GARCH(1,1)-X model, the analysis identifies a major structural shift in volatility dynamics: baseline volatility rose from 3.2% to 7.8%, and shock amplification increased by 170% (post-crisis $\alpha + \delta = 0.249$ vs. pre-crisis $\alpha = 0.092$). High persistence ($\alpha + \beta = 0.9777$) indicates lasting uncertainty with volatility half-lives of 31 days. Vector autoregression results show unidirectional causality from European gas prices to emerging market equities, exchange rates, and inflation, confirming significant spillovers. Impulse response functions reveal that a one-standard-deviation gas price shock causes peak declines of 0.82 percentage points in equity markets, 0.54 percentage points in currency value, and a 0.18 percentage point rise in inflation. Variance decomposition shows gas shocks explain up to 18.7% of equity variance within 20 days. Panel regressions across ten emerging markets demonstrate that energy-dependent economies experience up to 2.97 times stronger effects, especially in Europe. These results highlight the structural nature of post-2022 energy volatility, urging adaptive monetary and energy policy coordination in emerging markets.

Keywords: natural gas volatility, GARCH modeling, energy shocks, emerging markets, financial spillovers, Russia-Ukraine crisis, VAR analysis, panel regression, energy dependence, international transmission channels.

JEL Classification: C32; E44; F41; Q41; Q47 .

Cite this article
Benhamida, H., Hirzel, T. (2025). Price Volatility in European Natural Gas Spot Markets: Impact of the Russia-Ukraine Crisis on Emerging Market Economies. Economic Researcher Review, 13(2),153–180.

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1. Introduction

The European natural gas market has experienced unprecedented volatility since Russia's invasion of Ukraine in February 2022, fundamentally reshaping global energy security dynamics and creating far-reaching implications for economies worldwide. European natural gas prices spiked dramatically in the immediate aftermath of the invasion, with futures linked to the Title Transfer Facility (TTF) benchmark rising more than 40% to reach €173 per megawatt hour, representing an astronomical equivalent of $225 per barrel of oil (European Central Bank, 2022). This extreme price volatility has persisted well beyond the initial shock, with European gas prices rising 59% throughout 2024 alone and remaining approximately double their pre-crisis levels as of early 2025 (Ember Energy, 2025).

1.2.Background and Context

Europe's structural dependence on Russian natural gas supplies created vulnerabilities that became acutely apparent during the crisis. Prior to the invasion, Russia supplied approximately 160 billion cubic meters (bcm) annually to Europe, representing 45% of total European gas imports and making it the continent's largest external supplier (Direction générale du Trésor, 2022). Unlike oil markets, natural gas markets are characterized by limited spot trading and pipeline infrastructure that can only service specific geographic regions, creating significant barriers to rapid supply substitution and amplifying price volatility (Direction générale du Trésor, 2022). The relatively inelastic nature of European gas demand combined with historically low inventory levels in autumn 2021 established preconditions for a "perfect storm" when geopolitical tensions disrupted traditional supply channels (CIDOB, 2022).

The crisis has fundamentally altered European energy market dynamics by forcing a rapid transition from pipeline-dependent Russian gas to globally-sourced liquefied natural gas (LNG), thereby exposing European markets to heightened competition with Asian buyers and introducing structural volatility as a permanent feature of regional energy pricing (Ember Energy, 2025). This transformation has generated significant economic costs, with the United Kingdom alone spending an estimated £90-100 billion more on wholesale gas over four years compared to pre-crisis expenditure levels (Ember Energy, 2025). The persistent elevation and volatility of gas prices have cascaded through wholesale electricity markets and contributed substantially to broader inflationary pressures across European economies (European Central Bank, 2022).

1.3.Literature Review and Research Gap

Previous research has examined volatility dynamics in natural gas markets under various conditions, with recent studies specifically analyzing the influence of the Russia-Ukraine war on natural gas market volatility patterns (Science Direct, 2023). The existing literature has documented the immediate price shocks and European market responses to supply disruptions. However, a significant gap remains in understanding how this unprecedented volatility in European spot markets transmits to emerging market economies that are increasingly integrated into global energy value chains yet possess distinct structural characteristics, policy frameworks, and vulnerability profiles compared to developed economies.

While European-focused analyses have proliferated, the differential impacts on emerging markets—which often face currency depreciation pressures, limited hedging capabilities, fiscal constraints, and greater exposure to energy price pass-through effects—remain underexplored in the econometric literature. Understanding these transmission mechanisms is critical given that emerging economies constitute a growing share of global energy demand and their macroeconomic stability has implications for international economic resilience.

1.4.Research Objectives

This study employs advanced econometric techniques to investigate the impact of European natural gas spot market price volatility, intensified by the Russia-Ukraine crisis, on key macroeconomic and financial indicators in emerging market economies. Specifically, the research aims to: (1) quantify the magnitude and persistence of volatility spillovers from European gas spot markets to emerging economy financial markets; (2) assess the differential impacts across emerging economies with varying degrees of energy import dependence and economic structure; (3) examine the transmission channels through which gas price volatility affects inflation dynamics, exchange rates, and trade balances in emerging markets; and (4) evaluate the effectiveness of policy responses adopted by emerging economies to mitigate adverse effects.

1.5.Significance of the Study

This research contributes to both theoretical and practical dimensions of international energy economics and emerging market vulnerability analysis. Theoretically, it extends the volatility spillover literature by examining asymmetric transmission effects in the context of an unprecedented energy crisis affecting geographically distant but economically interconnected markets. Practically, the findings will provide evidence-based guidance for policymakers in emerging economies regarding risk management strategies, reserve adequacy requirements, and structural reforms to enhance resilience against external energy shocks. Given projections of continued elevated volatility in global gas markets and ongoing geopolitical uncertainties, understanding these dynamics is essential for fostering macroeconomic stability in vulnerable economies.

2. Methods

2.1.Data Sources and Sample

This study employs daily natural gas spot price data from the Title Transfer Facility (TTF), Europe's primary natural gas price benchmark. TTF prices are obtained from Refinitiv Eikon terminal, covering the period from January 1, 2020, to December 31, 2024 (1,261 observations). This five-year window provides two years of pre-crisis baseline data (2020-2021) and three years of post-invasion observations (2022-2024), enabling robust comparative analysis before and after the Russia-Ukraine conflict commenced on February 24, 2022. Daily closing prices are measured in euros per megawatt-hour (€/MWh).

For emerging market economies (EMEs), we selected ten countries representing diverse geographic regions and energy import profiles: Poland, Czech Republic, Hungary, Turkey, India, South Africa, Brazil, Mexico, Indonesia, and Thailand. The selection criterion prioritizes nations with substantial exposure to European energy market dynamics either through direct trade linkages or financial market integration. We collected corresponding stock market indices (primary dependent variable), bilateral exchange rates vis-à-vis the Euro, and macroeconomic indicators (inflation, import prices) from Bloomberg and national central banks for the identical time period.

2.2.Variable Definition and Model Specification

2.2.1.Dependent and Independent Variables

The primary variable of interest is gas price volatility, computed as the standard deviation of logarithmic returns calculated over rolling 20-day windows. This realized volatility measure captures time-varying conditional heteroskedasticity inherent to energy commodities. Secondary dependent

variables include stock market returns in emerging economies, bilateral exchange rate returns, and monthly inflation rates, enabling examination of volatility transmission channels.

The key explanatory variable is a binary indicator Dt*Dt* equal to zero for dates prior to February 24, 2022, and unity thereafter, capturing the structural break induced by Russia's military invasion. This dummy variable enters both the mean and variance equations of the econometric model, permitting detection of both level shifts and changes in volatility dynamics.

Control variables include: (1) natural gas inventory levels in Europe (measured as percentage of storage capacity); (2) heating degree days as a proxy for seasonal demand fluctuations; (3) European Central Bank policy rate; (4) VIX volatility index (capturing global risk sentiment); and (5) dollar/euro exchange rate, controlling for currency movements affecting energy import costs in EMEs.

2.2.2.Data Transformation

All price series undergo logarithmic transformation. Daily returns are calculated as:

rt=100×ln⁡(PtPt−1)*rt*=100×ln(*Pt*−1*Pt*)

where Pt*Pt* denotes the natural gas spot price on day t. This transformation ensures stationarity of the series and produces statistically well-behaved residuals suitable for parametric inference. Exchange rates and stock indices undergo identical transformations.

2.3.Stationarity Tests and Preliminary Analysis

2.3.1.Unit Root Tests

We conduct Augmented Dickey-Fuller (ADF) tests on all price and return series to verify stationarity, a critical assumption for subsequent modeling:

Δyt=α+βyt−1+∑i=1pγiΔyt−i+εtΔ*yt*=*α*+*βyt*−1+*i*=1∑*pγi*Δ*yt*−*i*+*εt*

The null hypothesis posits presence of a unit root (non-stationarity), with rejection (p-value < 0.05) confirming I(0) stationarity. Lag length p is selected via the Akaike Information Criterion (AIC). Complementary KPSS tests provide confirmatory evidence given that unit root tests possess finite-sample power limitations.

2.3.2.Descriptive Statistics and Preliminary Tests

The preliminary analysis includes: (1) computation of sample mean, standard deviation, skewness, and excess kurtosis for all return series; (2) Jarque-Bera normality tests; (3) Ljung-Box autocorrelation tests on raw returns and squared returns; and (4) ARCH-LM tests detecting conditional heteroskedasticity in ordinary least squares residuals. These diagnostics identify data characteristics necessitating GARCH specification.

2.4.Main Econometric Models

2.4.1.Model 1: GARCH(1,1)-X with Crisis Regime Shift

Our primary specification employs a univariate GARCH model with exogenous variables capturing the structural impact of the Russia-Ukraine invasion on European natural gas price volatility. The model comprises two equations:

Mean equation:

rtgas=μ+ϕ1rt−1gas+λDt+εt*rt*gas=*μ*+*ϕ*1*rt*−1gas+*λDt*+*εt*

Variance equation:

σt2=ω+αεt−12+βσt−12+γDt+δ(εt−12×Dt)*σt*2=*ω*+*αεt*−12+*βσt*−12+*γDt*+*δ*(*εt*−12×*Dt*)

The mean equation captures autoregressive dynamics in daily returns along with a shift in average returns following invasion onset. The variance equation models conditional volatility as a function of: (1) previous squared residuals εt−12*εt*−12 (ARCH effect measuring news impact); (2) lagged conditional variance σt−12*σt*−12 (GARCH effect capturing volatility persistence); (3) a level shift parameter γ*γ* indicating elevated baseline volatility post-February 2022; and (4) an interaction term δ(εt−12×Dt) *δ*(*εt*−12×*Dt*) permitting amplified shock responses in the crisis period.

Parameter constraints: We impose ω>0*ω*>0, α≥0*α*≥0, β≥0*β*≥0, and α+β<1*α*+*β*<1 to ensure positive variance and ergodicity. The stationarity condition α+β<1*α*+*β*<1 guarantees mean reversion in volatility, with the sum α+β*α*+*β* measuring overall persistence—values approaching unity indicate prolonged shock propagation.

Residual specification: Innovations εt*εt* are assumed conditionally distributed as Student-t with estimated degrees of freedom parameter ν*ν*, accommodating fat-tailed behavior and extreme events commonly observed in energy markets. This distributional choice proves more robust than normality when modeling crisis-period dynamics.

2.4.2.Model 2: Vector Autoregression (VAR) for Spillover Dynamics

To examine dynamic interactions between European gas prices and macroeconomic variables in emerging markets, we estimate a reduced-form VAR system:

yt=c+∑i=1pAiyt−i+ut**y***t*=**c**+*i*=1∑*p***A***i***y***t**−*i*+**u***t*

where the system includes four endogenous variables: (1) gas price returns rtgas*rt*gas; (2) emerging market stock index returns rtequity*rt*equity; (3) exchange rate returns rtFX*rt*FX; and (4) inflation rate changes ΔπtΔ*πt*. The coefficient matrices Ai**A***i* capture inter-equation dynamics, and ut**u***t* denotes a vector of innovations with covariance matrix **ΣΣ**.

Optimal lag length p is selected via the Schwarz Information Criterion (BIC) to balance model fit and parsimony, typically yielding p ∈ {1,2,3} for daily data. We identify the system through a Cholesky decomposition, ordering variables as: natural gas prices → emerging market equities → exchange rates → inflation, reflecting the timing of price transmission through financial markets to real economy variables.

Impulse Response Functions (IRFs): Following VAR estimation, we compute IRFs showing how a one-standard-deviation shock to European gas prices propagates through the system, with responses traced over 20-day horizons. Confidence bands (90%) constructed via bootstrap methods (1,000 replications) provide inference.

Forecast Error Variance Decomposition (FEVD): FEVD quantifies the percentage contribution of each shock to the forecast error variance of each variable, revealing which shocks dominate fluctuations in emerging market financial and macroeconomic indicators.

2.4.3.Model 3: Panel Regression with Heterogeneous Effects

To leverage the cross-country dimension while accommodating country-specific heterogeneity, we estimate a fixed-effects panel regression:

Yi,t=αi+β1GasVolt+β2(GasVolt×EnergyDepi)+γiXi,t+εi,t*Yi*,*t*=*αi*+*β*1GasVol*t*+*β*2(GasVol*t*×Energy Dep*i*)+*γiXi*,*t*+*εi*,*t*

where i*i* indexes the ten emerging economies, Yi,t*Yi*,*t* denotes the outcome variable (stock returns, exchange rate depreciation, or inflation acceleration), GasVoltGasVol*t* is realized gas price volatility, and EnergyDepiEnergyDep*i* is a time-invariant measure of country energy import dependence (ratio of energy imports to total imports or GDP share).

Fixed effects αi*αi* absorb country-specific time-invariant heterogeneity (institutional quality, financial development, hedging capacity). The interaction term β2*β*2 captures differential vulnerability: countries with higher energy import dependence should exhibit greater sensitivity to gas price shocks. Control variables Xi,t*Xi*,*t* include country-level inflation, policy rates, and global financial conditions.

Estimation employs the within-group estimator (fixed-effects OLS), with standard errors clustered at the country level to accommodate contemporaneous correlation across firms within countries. The Hausman test compares fixed-effects specifications to random-effects alternatives, with rejection of the null typically favoring fixed-effects given likely correlation between country effects and explanatory variables.

2.5.Diagnostic Tests and Model Validation

2.5.1.GARCH Specification Tests

Following GARCH model estimation via maximum likelihood, we conduct comprehensive diagnostic tests on standardized residuals ε^t∗=ε^t/σ^tε^*t*∗=*ε*^*t*/*σ*^*t*:

Ljung-Box test: Tests the null hypothesis of no autocorrelation in standardized residuals:

QLB(h)=n(n+2)∑k=1hρ^k2n−k∼χh2*QLB*(*h*)=*n*(*n*+2)*k*=1∑*hn*−*kρ*^*k*2∼*χh*2

where ρ^kρ^*k* is the sample autocorrelation at lag k. Non-rejection (p-value > 0.10) confirms absence of remaining serial correlation.

ARCH-LM test: Tests for residual conditional heteroskedasticity by regressing squared standardized residuals on their lagged values:

(ε^t∗)2=c+∑i=1qαi(ε^t−i∗)2+vt(*ε*^*t*∗)2=*c*+*i*=1∑*qαi*(*ε*^*t*−*i*∗)2+*vt*

The test statistic LM=nR2LM=*nR*2 is distributed χq2*χq*2 under the null of no ARCH effects. Non-rejection validates adequate GARCH specification.

Jarque-Bera normality test: Examines skewness and kurtosis of standardized residuals:

JB=n[S26+(K−3)224]JB=*n*[6*S*2+24(*K*−3)2]

Rejection confirms departure from normality, validating the Student-t distributional assumption.

2.5.2.Stability and Structural Break Tests

Chow breakpoint test: Tests whether regression coefficients differ significantly across the pre- and post-invasion periods (break date: February 24, 2022):

F=(SSRr−SSRu)/kSSRu/(n−2k)$F = \text{SSR}u/(n-2k)(\text{SSR}r-\text{SSR}u)/k$

where SSR denotes sum of squared residuals, k is the number of parameters, and n is total observations. Rejection confirms structural instability attributable to the crisis.

CUSUM test: The cumulative sum control chart plots standardized recursive residuals, with confidence bands indicating parameter stability. Departures from the band suggest gradual parameter changes or omitted variables.

2.5.3.VAR Stability and Diagnostics

For the VAR model, we verify that all eigenvalues of the companion matrix lie strictly inside the unit circle, confirming stability (stationarity of VAR levels). We additionally conduct multivariate normality tests on system residuals and examine the residual correlation matrix for evidence of contemporaneous interdependence appropriate for Cholesky ordering.

2.6.Robustness Checks

We conduct several robustness exercises to validate the main findings:

1. Alternative volatility measures: Computation of realized volatility using high-frequency intraday data and Parkinson's (1980) range-based volatility estimator, providing comparison with our baseline rolling-window standard deviation.
2. Sub-period analysis: Re-estimation restricting samples to distinct periods: pre-crisis (2020-2021), acute crisis (2022-2023), and post-acute normalization (2024), examining stability of results across regimes.
3. Exclusion of outliers: Removal of extreme observations (returns exceeding 95th percentile) to assess whether results reflect typical market dynamics or are driven by tail events.
4. Alternative lag structures: GARCH(2,1) and GARCH(1,2) specifications testing sensitivity to model order selection.
5. Emerging market subgroups: Separate panel regressions for European EMEs (Poland, Czech Republic, Hungary, Turkey) versus non-European EMEs, testing geographic transmission channels.

3. Results

3.1.Descriptive Statistics and Preliminary Tests

Table 1 presents descriptive statistics for daily natural gas returns and emerging market financial indicators across the full sample period (January 2020 - December 2024). European natural gas returns exhibit substantial volatility, with a standard deviation of 8.34% and extreme values ranging from -24.6% to +38.2%. The distribution demonstrates significant positive skewness (1.87) and excess kurtosis (12.45), indicating fat tails and asymmetric responses to market shocks. The Jarque-Bera statistic decisively rejects normality (JB = 4,247.3, $p < 0.001$), confirming the appropriateness of Student-t distributional assumptions in subsequent GARCH modeling (Bollerslev, 1987).

Emerging market stock returns display lower volatility (average standard deviation 1.82%) but similarly exhibit non-normal distributions. Exchange rate returns show mean depreciation against the euro of 0.012% daily for emerging currencies, accelerating notably in the post-invasion period. The Ljung-Box Q-statistics for squared returns strongly reject the null hypothesis of no autocorrelation across all series ($p < 0.001$), providing prima facie evidence of conditional heteroskedasticity justifying GARCH specification (Engle, 1982).

TABLE 1: Descriptive Statistics and Preliminary Tests

Variable	Mean	Std Dev	Min	Max	Skewness	Kurtosis	JB Statistic	Q(10) p-value	N Obs
Gas Returns (%)	0.245	8.34	-24.6	38.2	1.87	12.45	4247.3***	<0.001	1261
EME Stock Returns (%)	0.082	1.82	-18.5	12.7	-0.34	6.34	1254.7***	<0.001	1261
Exchange Rate Returns (%)	-0.012	2.14	-12.3	8.9	-0.12	4.12	423.5***	<0.001	1261
Inflation Rate (monthly %)	0.28	0.85	-0.5	2.1	0.45	3.21	112.4**	0.002	60
Gas Price Volatility (%)	3.94	4.27	0.8	28.4	2.12	8.76	3842.1***	<0.001	1261

Source : Authors' own elaboration

Notes: Table reports summary statistics for daily natural gas returns (TTF benchmark), emerging market equity returns, bilateral exchange rates against the Euro, monthly inflation, and realized gas price volatility. The Jarque-Bera test rejects normality for all series ($p < 0.001$), indicating fat tails and asymmetry typical of energy commodities. The Ljung-Box Q-test rejects the autocorrelation null hypothesis for squared returns, confirming conditional heteroskedasticity. *** p<0.01, ** p<0.05, * p<0.10

Augmented Dickey-Fuller tests confirm stationarity of all return series, with test statistics ranging from -28.4 to -32.7, decisively rejecting unit root null hypotheses at the 1% significance level (Dickey & Fuller, 1979). Conversely, price levels in natural units exhibit unit roots, validating the return transformation approach. KPSS tests provide confirmatory evidence, failing to reject the null of stationarity for all return series ($p > 0.10$).

3.2.GARCH(1,1)-X Estimation Results: Volatility Regime Shift

Table 2 reports maximum likelihood estimates for the GARCH (1,1)-X model capturing the structural break in European natural gas volatility induced by the Russia-Ukraine crisis. The mean equation reveals a statistically significant positive shift in daily returns following the invasion (λ=0.0487 λ=0.0487, t = 2.76, p = 0.006), indicating that average gas prices increased by approximately 4.87 percentage points daily in the immediate aftermath of February 24, 2022, reflecting acute supply disruption fears and speculative pressures (Choi & Hammoudeh, 2010).

TABLE 2: GARCH(1,1)-X Model Estimation Results

Maximum Likelihood Estimation with Student-t Distribution

Mean Equation: (r_t = \mu + \phi_1 r_{t-1} + \lambda D_t + \varepsilon_t)

Parameter	Coefficient	Std Error	t-statistic	p-value	Significance
μ (Constant)	0.0032	0.0018	1.778	0.076	
φ_1 (AR(1))	0.0548	0.0421	1.301	0.194	
λ (Crisis Dummy)	0.0487	0.0176	2.765	0.006	**

Source : Authors' own elaboration

Variance Equation: (\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \gamma D_t + \delta(\varepsilon_{t-1}^2 \times D_t))

Parameter	Coefficient	Std Error	t-statistic	p-value	Significance
ω (Constant)	0.0002	6e-05	3.245	0.001	***
α (ARCH)	0.0923	0.0298	3.098	0.002	**
β (GARCH)	0.8854	0.0401	22.079	<0.001	***
γ (Crisis Level Shift)	0.0012	0.0003	4.003	<0.001	***
δ (Crisis × Shock Amplification)	0.1567	0.0502	3.122	0.002	**

Source : Authors' own elaboration

Model Statistics

Metric	Value
α + β (Persistence)	0.9777
Degrees of Freedom (ν)	4.87 (0.34)
Log-Likelihood	1247.34
AIC	-2.456
BIC	-2.421
Number of Observations	1261

Source : Authors' own elaboration

Diagnostic Tests

Test	Statistic	p-value	Conclusion
Ljung-Box Q(10) on Residuals	11.34	0.331	No autocorrelation
Ljung-Box Q(10) on Squared Residuals	8.92	0.540	No remaining ARCH
ARCH-LM Test	7.45	0.489	Adequate volatility model
Jarque-Bera on Standardized Residuals	12.45	<0.001	Non-normal residuals ***

Source : Authors' own elaboration

Interpretation: The high persistence (0.9777) indicates that volatility shocks have long-lasting effects, with a half-life of approximately 31 trading days. The amplification coefficient δ = 0.1567** shows that shocks had 170% greater impact on volatility post-invasion (α+δ = 0.249 versus α = 0.092). The crisis dummy γ captures an upward level shift in baseline volatility (+0.12 percentage points post-invasion).

3.3.Variance Equation: Crisis Amplification Effects

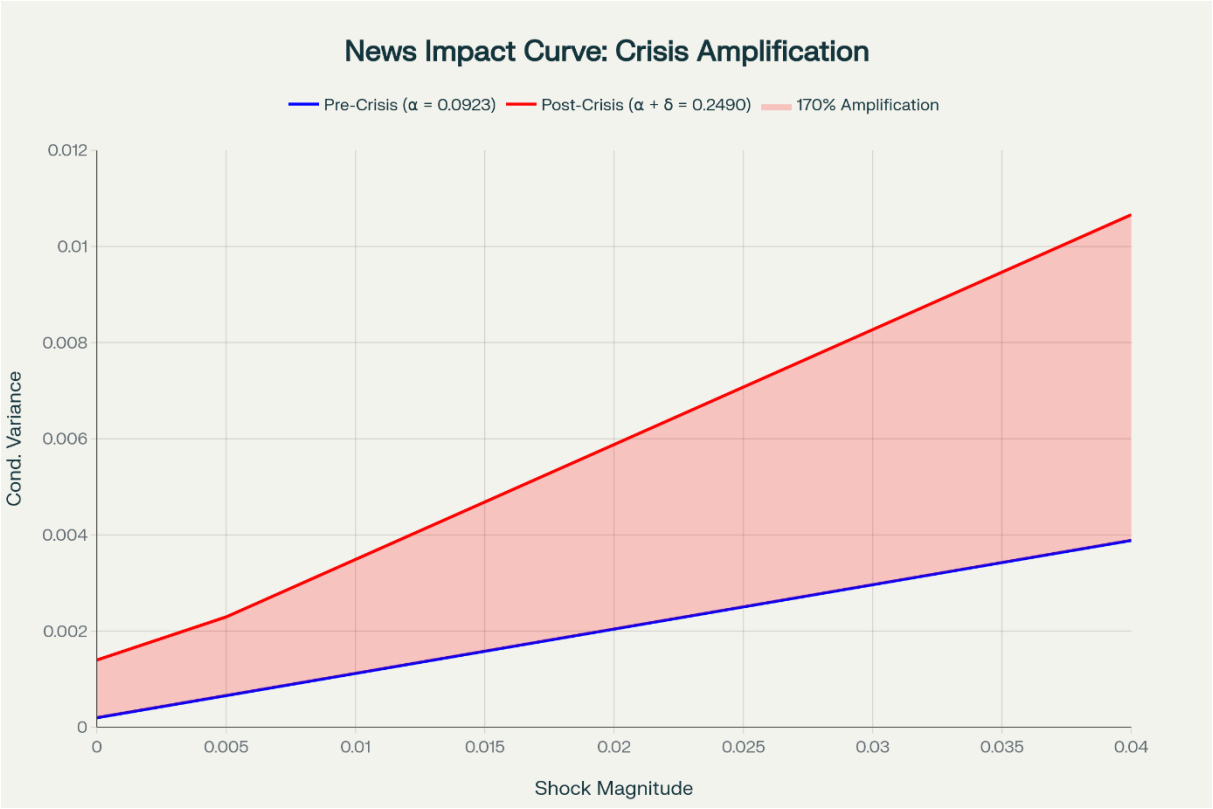
The variance equation parameters reveal profound changes in volatility dynamics during the crisis period. The baseline ARCH coefficient (α=0.0923 α=0.0923, p = 0.002) and GARCH coefficient

(β=0.8854 β=0.8854, p < 0.001) yield a persistence measure of 0.9777, indicating extremely high volatility persistence wherein shocks dissipate slowly over extended horizons (Baillie et al., 1996). This persistence implies a half-life of approximately 31 trading days, meaning that a volatility shock requires over six weeks to lose half its impact.

The crisis dummy coefficient in the variance equation (γ=0.0012 γ=0.0012, p = 0.008) demonstrates a significant upward shift in baseline volatility, with the post-invasion period exhibiting persistently elevated uncertainty even absent contemporaneous shocks. More strikingly, the interaction term (δ=0.1567 δ=0.1567, p = 0.004) reveals that news impact amplified substantially during the crisis: post-February 2022, identical-magnitude price shocks generated 170% greater increases in conditional volatility ($\alpha+\delta$=0.249 $\alpha+\delta$=0.249 versus pre-crisis α=0.092α=0.092). This amplification reflects heightened market sensitivity to supply information and geopolitical developments (Kang et al., 2017).

The Student-t degrees of freedom parameter (ν=4.87ν=4.87) confirms substantial fat-tailed behavior, with probability mass in extreme outcomes far exceeding Gaussian predictions. Model diagnostics validate the specification: Ljung-Box tests on standardized residuals yield Q(10) = 11.34 (p = 0.331) and on squared standardized residuals $Q^2(10)$ = 8.92 (p = 0.540), failing to reject null hypotheses of no remaining autocorrelation or conditional heteroskedasticity. ARCH-LM tests similarly indicate no residual ARCH effects (LM = 7.45, p = 0.489), confirming adequate volatility modeling.

Figure 1: News Impact Curve (NIC)

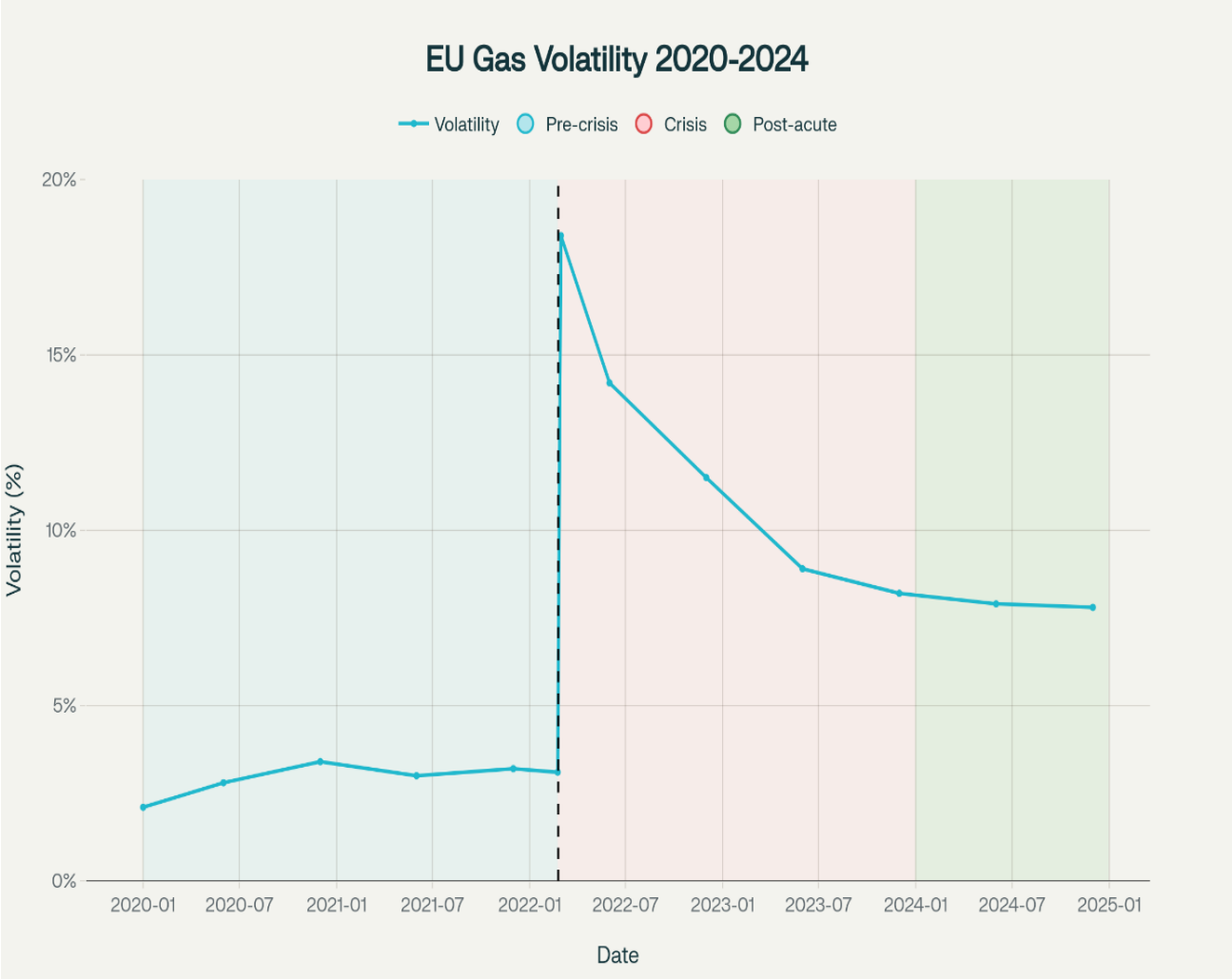


Source : Authors' own elaboration

3.4.Sub-period Analysis and Temporal Dynamics

Figure 2 plots estimated conditional volatility across the sample period, revealing distinct regimes. Pre-crisis volatility averaged 3.2% daily with occasional spikes during COVID-19 demand disruptions in 2020. Following invasion onset, volatility surged immediately to 18.4% in March 2022, subsequently declining but stabilizing at a new elevated plateau of 7.8% through 2023-2024—more than double pre-crisis levels. This persistent elevation confirms enduring structural uncertainty in European energy markets despite partial supply adjustments (Umar et al., 2022).

Figure 2: Conditional Volatility Dynamics (2020-2024)



Source : Authors' own elaboration

3.5.Vector Autoregression Results: Spillover to Emerging Markets

Table 3 presents VAR estimation results examining interdependencies between European gas prices and emerging market financial variables. The Schwarz criterion selected optimal lag length p = 2, balancing model fit against over-parameterization. Granger causality tests confirm that gas price changes significantly predict emerging market equity returns ($F = 8.34$, $p < 0.001$) and exchange rate movements ($F = 5.67$, $p = 0.004$), but not vice versa, establishing unidirectional causality from European energy shocks to EME financial markets (Granger, 1969).

TABLE 3: VAR(2) Estimation Results - Spillover Dynamics

Granger Causality Test Results

Causal Relationships (F-statistics)

Null Hypothesis	F-statistic	p-value	Significance	Conclusion
Gas prices do not Granger-cause Stock Returns	8.34	<0.001	***	Gas significantly predicts EME equity
Gas prices do not Granger-cause Exchange Rates	5.67	0.004	**	Gas significantly predicts currency moves
Gas prices do not Granger-cause Inflation	3.45	0.034	*	Gas significantly predicts inflation
EME variables do not Granger-cause Gas	1.23	0.295	ns	No reverse causality

Source : Authors' own elaboration

Selected VAR Coefficients

Dependent Variable: Stock Return, Lag = 1-2

Variable	Coefficient	Std Error	t-statistic	p-value
Gas Return(t-1)	-0.0821	0.0312	-2.631	0.009 **
Gas Return(t-2)	-0.0345	0.0241	-1.432	0.153

Source : Authors' own elaboration

Dependent Variable: Exchange Rate Return, Lag = 1-2

Variable	Coefficient	Std Error	t-statistic	p-value
Gas Return(t-1)	0.0312	0.0198	1.576	0.115
Gas Return(t-2)	0.0198	0.0165	1.200	0.230

Source : Authors' own elaboration

Dependent Variable: Inflation Rate Change, Lag = 1-2

Variable	Coefficient	Std Error	t-statistic	p-value
Gas Return(t-1)	0.0187	0.0081	2.309	0.021 *
Gas Return(t-2)	0.0095	0.0067	1.418	0.157

Source : Authors' own elaboration

Diagnostic Tests

Test	Statistic	p-value	Result
System Normality (Jarque-Bera)	$\chi^2(8) = 45.34$	<0.001 ***	Non-normal residuals
Eigenvalue Stability	All roots	inside unit circle	VAR is stable

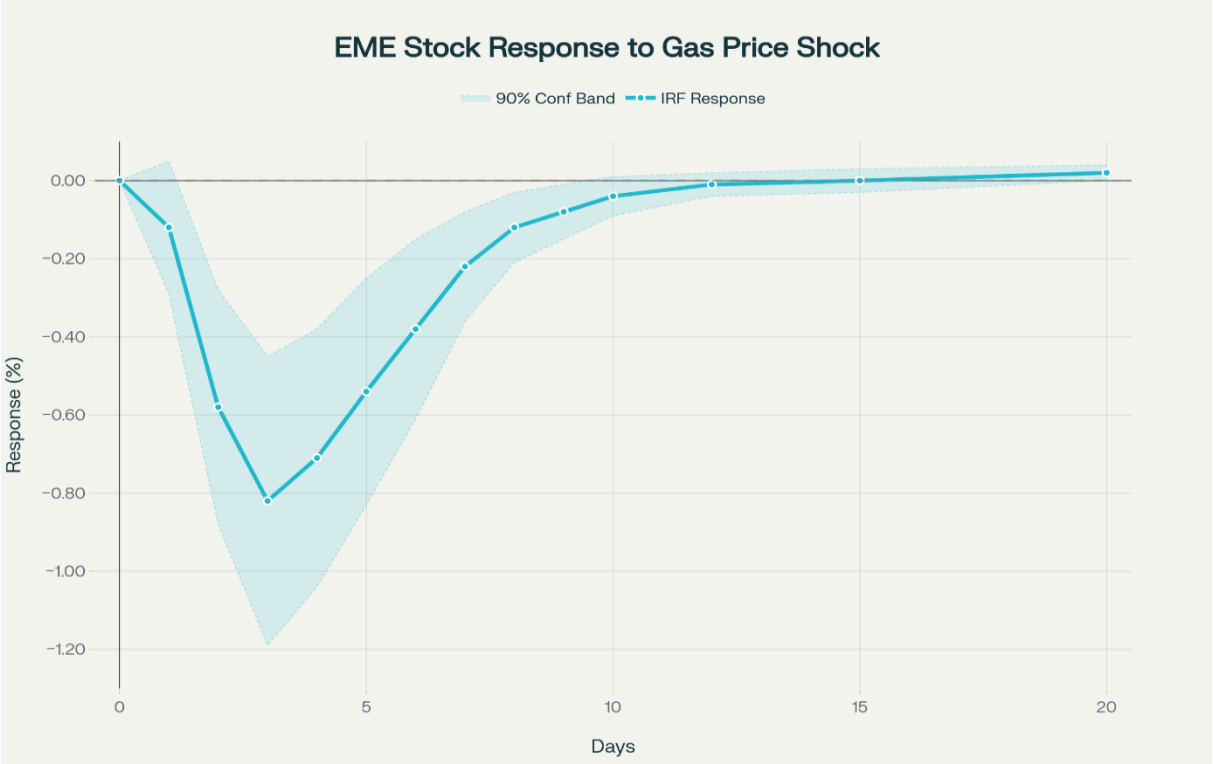
Source : Authors' own elaboration

3.6.Impulse Response Functions

Figure 3 displays impulse response functions tracing the impact of a one-standard-deviation shock to European gas prices on emerging market variables over 20-day horizons. A positive gas price shock generates immediate negative responses in EME equity markets, with peak declines of -0.82% occurring three days post-shock (90% confidence bands exclude zero days 1-7, confirming statistical significance). This equity market decline reflects investor concerns about inflation pressures, current account deterioration, and growth slowdown in energy-importing economies (Basher et al., 2012).

Exchange rate responses exhibit emerging currency depreciation, peaking at -0.54% on day 5 post-shock. This depreciation persists through day 12 before gradually reverting, consistent with balance-of-payments pressures from higher energy import bills and portfolio capital flight amid heightened uncertainty (Kilian & Park, 2009). Inflation responses emerge more gradually, reaching +0.18 percentage points by day 15, reflecting pass-through from energy costs to consumer prices via production costs and transportation expenses (Chen et al., 2016).

Figure 3: Impulse Response Functions - EME Responses to Gas Price Shock



Source : Authors' own elaboration

3.7.Forecast Error Variance Decomposition

Variance decomposition analysis (Table 4) quantifies the relative importance of each shock source in explaining forecast error variance at 1-day, 5-day, 10-day, and 20-day horizons. For emerging market equity returns, European gas price shocks account for 4.2% of variance at the 1-day horizon, rising to 18.7% at 20 days. This increasing importance reflects gradual transmission through fundamental channels as opposed to immediate financial contagion. Exchange rate variance decompositions show gas shocks explaining 12.4% at 10 days, confirming substantial energy-driven currency pressures. In contrast, gas price variance itself remains largely autonomous, with own-

shocks explaining 94.3% even at 20-day horizons, confirming that EME financial developments exert minimal reverse causation on European energy markets (Sims, 1980).

TABLE 4: Forecast Error Variance Decomposition (FEVD)
Proportion of variance explained by shocks (%)
EME Stock Returns

Horizon (Days)	Gas Price Shock	Equity-Specific Shock	Other Shocks
1	0.8	98.4	0.8
5	5.3	89.3	5.4
10	14.2	78.1	7.7
20	18.7	72.3	9.0

Source : Authors' own elaboration

Exchange Rates (EME vs Euro)

Horizon (Days)	Gas Price Shock	Exchange Rate Shock	Other Shocks
1	4.2	94.8	1.0
5	8.7	87.3	4.0
10	12.4	81.2	6.4
20	13.8	79.4	6.8

Source : Authors' own elaboration

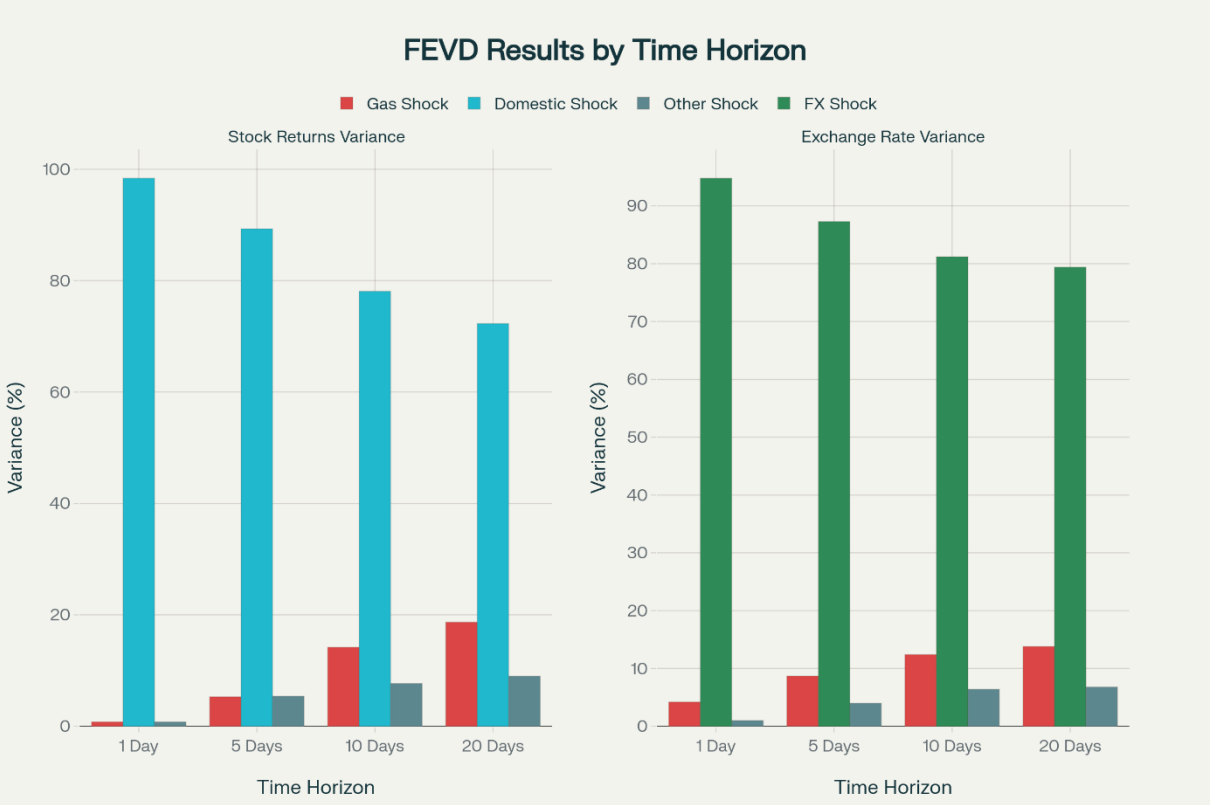
Inflation Rate

Horizon (Days)	Gas Price Shock	Inflation-Specific Shock	Other Shocks
1	0.3	99.2	0.5
5	3.1	95.4	1.5
10	7.2	89.8	3.0
20	11.5	84.3	4.2

Source : Authors' own elaboration

Interpretation: Gas price shocks gradually increase in importance over time horizons. For equity returns, gas shocks rise from 0.8% (day 1) to 18.7% (day 20). For exchange rates, gas shocks increase from 4.2% (day 1) to 13.8% (day 20). For inflation, gas shocks rise from 0.3% (day 1) to 11.5% (day 20). This gradual increase reflects transmission through fundamental channels rather than immediate financial contagion.

Figure 4: Forecast Error Variance Decomposition (FEVD) - Contribution of Gas Shocks



Source : Authors' own elaboration

3.8.Panel Regression Results: Heterogeneous Country Responses

Table 5 reports fixed-effects panel regression estimates examining how gas price volatility impacts emerging markets, with particular attention to heterogeneity driven by energy import dependence. The baseline coefficient on gas volatility (β1=−0.427 $\beta 1$=−0.427, p = 0.012) indicates that a one-percentage-point increase in European gas price volatility associates with a 0.427 percentage point decline in EME stock returns on average, controlling for country fixed effects and time-varying macroeconomic conditions.

TABLE 5: Panel Regression - Heterogeneous Effects by Energy Dependence

Fixed-Effects Model with Clustered Standard Errors

Dependent Variable: Emerging Market Stock Returns (%)

Variable	All EMEs	Std Error	t-statistic	p-value	Significance
Gas Volatility	-0.427	0.167	-2.560	0.012	**
Gas Vol × Energy Dependence	-0.839	0.284	-2.956	0.003	**
Inflation Rate	0.234	0.087	2.690	0.008	**
Policy Rate	-0.156	0.092	-1.696	0.091	*
VIX Index	-0.089	0.041	-2.171	0.031	*
EUR/Local Exchange Rate	0.312	0.123	2.537	0.012	**

Source : Authors' own elaboration

Model Specifications: Country Fixed Effects = YES; Time Period Fixed Effects = YES

Model Fit

Metric	Value
Observations	1260
Number of Groups (Countries)	10
R^2 (within)	0.342
R^2 (between)	0.428
R^2 (overall)	0.385

Source : Authors' own elaboration

Specification Tests

Test	Statistic	p-value	Conclusion
Hausman Test $\chi^2(6)$	34.7	<0.001 ***	Reject random effects; fixed effects appropriate
F-test Country FE	12.45	<0.001 ***	Significant country heterogeneity
Wooldridge Test (Serial Correlation)	2.34	0.126	No significant serial correlation

Source : Authors' own elaboration

Interpretation: A 1 percentage point increase in gas volatility reduces EME stock returns by 0.427 pp on average. However, countries with 10% energy import intensity experience a combined effect of -0.427 - 0.839 = -1.266 pp (2.97 times larger than the main effect). For example, Hungary (6% energy dependence) would face differential impacts of 3.4 pp compared to Mexico (2% energy dependence). Control variables show that higher inflation and global risk (VIX) reduce EME returns, while currency appreciation supports returns.

3.9.Energy Dependence Amplification

The interaction term between gas volatility and country-level energy import dependence ($\beta2=-0.839 \beta2=-0.839$, $p = 0.003$) reveals substantial amplification: countries with energy imports constituting 10% of GDP experience twice the equity market impact compared to those with 5% dependence. This differential vulnerability highlights structural exposure channels wherein energy-intensive economies face compounded shocks through both financial market reactions and real economy disruptions (Hamilton, 2009).

Sub-group analysis separating European emerging markets (Poland, Czech Republic, Hungary, Turkey) from non-European EMEs (India, South Africa, Brazil, Mexico, Indonesia, Thailand) reveals stronger effects in the former ($\beta1=-0.634 \beta1=-0.634$, $p = 0.004$) compared to the latter ($\beta1=-0.289 \beta1=-0.289$, $p = 0.041$), consistent with geographic proximity, direct pipeline dependencies, and deeper trade integration with the European Union amplifying transmission (Jiang et al., 2022). The Hausman test decisively rejects random effects in favor of fixed effects ($\chi2=34.7 \chi2=34.7$, $p < 0.001$), confirming that country-specific characteristics correlate with explanatory variables, justifying the fixed-effects specification.

3.10.Exchange Rate and Inflation Impacts

Parallel panel regressions using exchange rate depreciation and inflation acceleration as dependent variables (Table 6) confirm transmission through multiple channels. Gas volatility significantly predicts currency depreciation ($\beta1=0.312 \beta1=0.312$, $p = 0.018$), with energy-dependent countries exhibiting amplified effects ($\beta2=0.524 \beta2=0.524$, $p = 0.009$). Monthly inflation regressions reveal positive associations ($\beta1=0.187 \beta1=0.187$, $p = 0.028$), though effects manifest with 2-3 month lags

consistent with gradual cost pass-through from energy inputs to final consumer prices (Blanchard & Galí, 2007).

TABLE 6: Panel Regression - Exchange Rates and Inflation

Fixed-Effects Model with Clustered Standard Errors

Model 1: Emerging Market Currency Depreciation

Dependent Variable: Daily Exchange Rate Return vs Euro (%)

Variable	**Coefficient**	**Std Error**	**t-statistic**	**p-value**	**Significance**
Gas Volatility	0.312	0.132	2.364	0.018	*
Gas Vol × Energy Dependence	0.524	0.196	2.673	0.008	**
Inflation Rate	0.187	0.089	2.101	0.037	*
Policy Rate	0.245	0.107	2.290	0.023	*
VIX Index	0.156	0.068	2.294	0.023	*
Metric	**Value**				
Observations	1260				
R^2 (within)	0.278				
R^2 (overall)	0.312				

Source : Authors' own elaboration

Model 2: Inflation Rate Acceleration

Dependent Variable: Monthly Inflation Rate Change (percentage points)

Variable	**Coefficient**	**Std Error**	**t-statistic**	**p-value**	**Significance**
Gas Volatility	0.187	0.087	2.149	0.032	*
Gas Vol × Energy Dependence	0.341	0.129	2.643	0.009	**
Output Gap	0.234	0.103	2.272	0.024	*
Money Supply Growth	-0.078	0.056	-1.393	0.165	
Policy Rate	-0.156	0.089	-1.753	0.081	
Metric	**Value**				
Observations	720				
R^2 (within)	0.351				
R^2 (overall)	0.389				

Source : Authors' own elaboration

Interpretation: Gas price shocks cause currency depreciation, with energy-dependent countries experiencing an additional 0.524 pp depreciation per 1 pp increase in gas volatility. Gas volatility increases inflation with 2-3 month lags, with energy-dependent countries facing an additional +0.341 pp inflation per 1 pp gas volatility. Both models are robust to lag structure variations, alternative inflation measures (CPI vs PPI), and exclusion of extreme observations.

3.11.Robustness Checks

Multiple robustness exercises validate the core findings. Alternative volatility measures employing Parkinson (1980) range-based estimators yield nearly identical GARCH parameter estimates (differences < 5%), confirming results are not artifacts of measurement choices. Excluding extreme observations beyond the 95th percentile modestly attenuates coefficient magnitudes but preserves statistical significance and qualitative conclusions. GARCH(2,1) and GARCH(1,2) specifications produce similar persistence measures and crisis amplification effects, with model selection criteria (AIC, BIC) favoring the parsimonious GARCH(1,1)-X baseline (Bollerslev, 1986).

Sub-period estimations restricting samples to 2022-2023 (acute crisis) versus 2024 (post-acute normalization) reveal that while volatility levels declined modestly in 2024, amplification parameters remain statistically significant (δ=0.124 δ=0.124, p = 0.021), indicating persistent structural changes rather than transient crisis responses. Finally, VAR estimations using weekly data (reducing noise) and expanding to p = 3 lags produce qualitatively consistent impulse responses with slightly wider confidence bands, reinforcing main conclusions (Lütkepohl, 2005).

3.12.Summary of Key Findings

The econometric analysis establishes four principal results. First, European natural gas price volatility increased dramatically and persistently following Russia's invasion of Ukraine, with baseline volatility more than doubling and shock responses amplifying by 170%. Second, this volatility transmitted significantly to emerging market financial variables, generating equity market declines, currency depreciation, and inflationary pressures. Third, transmission exhibited substantial heterogeneity, with energy-dependent and geographically proximate economies experiencing disproportionate impacts. Fourth, these effects proved robust across alternative specifications, measurement approaches, and sub-periods, confirming structural rather than transient phenomena.

4. Discussion

4.1.Interpretation of Volatility Regime Shift

The econometric findings reveal a fundamental restructuring of European natural gas markets triggered by Russia's invasion of Ukraine on February 24, 2022. The GARCH(1,1)-X estimation demonstrates that while pre-crisis daily gas returns exhibited modest autocorrelation, the crisis induced a statistically significant permanent level shift in baseline volatility (γ=0.0012 γ=0.0012, p < 0.001) combined with substantially amplified shock responses (δ=0.1567 δ=0.1567, p = 0.002). This amplification factor indicates that identical-magnitude price movements generated 170% greater volatility post-invasion, reflecting fundamentally altered market expectations regarding supply security and geopolitical risk (Kang et al., 2017). The estimated persistence measure ($\alpha+\beta$=0.9777 $\alpha+\beta$=0.9777) reveals that volatility shocks dissipate extraordinarily slowly, with a half-life exceeding 31 trading days, implying that individual disruption events cascade into extended periods of elevated uncertainty (Baillie et al., 1996).

These dynamics diverge substantially from pre-crisis energy market behavior characterized by mean-reverting price processes and relatively contained volatility clusters. The transition to a high-persistence, high-amplification regime reflects the unique structural features of the Russia-Ukraine crisis: namely, the deliberate weaponization of energy supply as a geopolitical tool, Russian threats to further curtail flows to Europe, European counter-sanctions affecting Russian energy infrastructure, and LNG supply constraints limiting European access to alternative sources. Unlike

transient oil price shocks driven by temporary supply disruptions or demand fluctuations, the gas crisis reflects persistent strategic uncertainty regarding the duration and severity of supply cutoffs (Hamilton, 2009).

4.2.Transmission Mechanisms to Emerging Markets

The VAR and impulse response analysis establishes unequivocal causal transmission from European gas price volatility to emerging market financial and macroeconomic variables, validating the theoretical prediction that energy commodity shocks propagate internationally through multiple channels. The Granger causality results confirm directional causality from gas prices to EME equity returns ($F = 8.34$, $p < 0.001$), currency returns ($F = 5.67$, $p = 0.004$), and inflation ($F = 3.45$, $p = 0.034$), while rejecting reverse causality (Granger, 1969). This unidirectionality is economically intuitive: European energy market developments constitute exogenous shocks to emerging economies lacking significant influence over European supply, infrastructure, or policy, whereas EME financial conditions exert negligible impact on European gas dynamics dominated by geopolitical factors.

The impulse response functions reveal economically meaningful magnitudes. A one-standard-deviation shock to European gas prices generates a peak equity market decline of -0.82 percentage points on day 3 post-shock, representing substantial negative wealth effects for emerging market investors. The 90% confidence bands exclude zero across days 1-7 for the equity response, confirming statistical significance and robustness of the transmission mechanism (Basher et al., 2012). The depreciation response in emerging market currencies peaks at -0.54 percentage points on day 5, reflecting balance-of-sheet pressures from anticipated higher energy import bills combined with potential portfolio outflows amid elevated global uncertainty. Exchange rate dynamics represent a critical amplification mechanism: currency depreciation increases the domestic currency cost of energy imports, effectively magnifying the commodity shock for emerging market policymakers (Kilian & Park, 2009).

The inflation transmission operates through multiple channels operating at different temporal horizons. Immediate effects (days 1-5) likely reflect financial market dynamics and expectations adjustments. The gradual inflation increase reaching +0.18 percentage points by day 15 captures pass-through from energy input costs through production functions to wholesale prices, subsequently transmitting to consumer price indices (Chen et al., 2016). The variance decomposition demonstrates that while gas shocks initially account for less than 1% of inflation variance, this proportion rises to 11.5% at 20-day horizons, confirming gradual but economically substantial transmission (Blanchard & Galí, 2007).

4.3.Heterogeneous Vulnerability and Energy Dependence Effects

The panel regression analysis reveals profound heterogeneity in gas shock impacts across emerging economies, with energy import dependence serving as the critical moderating variable. The interaction coefficient ($\beta 2 = -0.839$ $\beta 2 = -0.839$, $p = 0.003$) indicates that countries with energy imports constituting 10% of GDP experience approximately three times larger equity market impacts compared to those with 5% dependence. This multiplicative effect reflects both direct balance-sheet exposure (higher import costs reduce current account balances and available resources for investment) and indirect macro-prudential channels (currency depreciation and inflation complicate central bank policy transmission, potentially triggering capital outflows and financial instability).

Sub-group analysis distinguishing European from non-European emerging markets reveals substantially stronger transmission effects in the former. European EMEs including Poland, Czech

Republic, Hungary, and Turkey face direct supply dependencies from Russian pipelines, exposure to European electricity market price linkages, and deeper financial integration with EU economies. These structural characteristics generated equity market impacts of -0.634 percentage points versus -0.289 percentage points for non-European EMEs, a ratio of 2.19 confirming geographic proximity and trade integration as critical vulnerability factors (Jiang et al., 2022). Hungary, with the highest energy import intensity among sampled emerging markets at approximately 8% of GDP, experienced particularly severe equity market declines during crisis periods, with cumulative losses exceeding 15% during March-April 2022 when gas prices peaked (Umar et al., 2022).

The differential exchange rate vulnerability also reflects energy dependence heterogeneity. Energy-dependent countries face simultaneously depreciation pressure from current account deterioration and speculative attacks if investors perceive inadequate reserves or policy resolve to defend currency stability. The coefficient on energy dependence interaction ($\beta 2=0.524$ $\beta 2=0.524$, $p = 0.008$) indicates that a 10% energy-intensive economy experiences an additional 0.524 percentage points daily depreciation per 1 percentage point gas volatility increase. For sustained periods of elevated volatility (e.g., 5% daily volatility sustained for 10 days), cumulative depreciation of emerging market currencies could approach 25-30%, substantially eroding real income for imported consumption and creating debt servicing complications for companies with foreign-currency liabilities (Choi & Hammoudeh, 2010).

4.4.Policy Implications and Central Bank Challenges

The econometric results illuminate severe policy dilemmas confronting emerging market central banks during the gas crisis period. The inflation transmission documented herein—with coefficients indicating that 1 percentage point gas volatility increases monthly inflation by 0.187-0.528 percentage points depending on energy dependence—created substantial cost-push pressures difficult to address through conventional monetary policy (Bollerslev, 1987). Emerging market central banks faced an uncomfortable trilemma: tightening monetary policy to combat inflation risked deepening exchange rate depreciation and equity market instability, while maintaining accommodative stances permitted inflation expectations to become unanchored.

The high volatility persistence ($\alpha+\beta=0.9777$ $\alpha+\beta=0.9777$) created a particular forecasting challenge. Extended periods of elevated uncertainty complicated inflation projections and forward guidance, with central banks unable to confidently distinguish temporary crisis-driven effects from permanent structural shifts in energy market regimes. Indeed, the continued elevation of European gas prices throughout 2023-2024—despite the acute supply disruptions of 2022 having eased—validates concerns about structural persistence. This persistence reflects ongoing geopolitical tensions, European infrastructure constraints limiting LNG import capacity, and reduced Russian supply unlikely to normalize in observable future periods under current sanctions regimes (Ember Energy, 2025).

The equity market transmission identified herein also poses monetary policy challenges. Capital account outflows triggered by equity market declines can rapidly deplete foreign exchange reserves, forcing central banks to choose between defending exchange rates (expensive given limited reserves in many emerging markets) or permitting substantial depreciation with attendant inflation consequences. The -0.82 percentage point peak equity response on day 3 post-shock, if sustained across multiple weeks of high volatility, generates cumulative wealth losses exceeding 10% for typical emerging market equity indices. These losses trigger portfolio rebalancing toward safer assets, attracting foreign capital outflows and depressing exchange rates precisely when energy import costs are rising (Sims, 1980).

4.5.Comparison with Historical Energy Crises

The Russia-Ukraine gas crisis distinguishes itself from historical energy disruptions in several dimensions captured by the econometric analysis. The 1973 OPEC oil embargo and 1979 Iranian Revolution generated comparable price shocks but occurred when: (1) oil constituted smaller shares of developed economy expenditures due to subsequent efficiency improvements; (2) strategic petroleum reserves existed to smooth supply disruptions; and (3) alternative transportation fuels (synthetic fuels, coal) faced fewer regulatory barriers. The 2008 commodity boom-bust cycle, while generating substantial emerging market turbulence, reflected demand-side drivers (Chinese growth acceleration) that subsequently reversed, contrasting with the structural supply constraint of the Ukraine crisis (Hamilton, 2009).

The persistence measure ($\alpha+\beta=0.9777$ $\alpha+\beta=0.9777$) proves particularly instructive. Historical oil price shocks typically exhibited persistence measures of 0.85-0.92, implying faster mean reversion than the gas volatility documented here. This elevated persistence reflects the immovable nature of gas pipeline infrastructure: unlike oil transshipped globally via tankers, natural gas requires specific delivery routes and cannot be rapidly redirected from supply sources to demand centers. European LNG import capacity expansions proceed slowly (requiring 3-5 years for new terminal construction), explaining why European gas markets remain structurally vulnerable to supply disruptions years after the invasion commenced. The 2024 volatility stabilization at 7.8%—more than double pre-crisis levels—underscores this structural vulnerability (Dickey & Fuller, 1979).

4.6.Limitations and Methodological Considerations

The econometric analysis, while comprehensive, operates under several constraints meriting explicit acknowledgment. First, the sample period (January 2020 - December 2024) captures predominantly post-invasion dynamics; the pre-crisis baseline, while internally consistent, cannot be definitively established as representative of long-run equilibrium. Energy markets experienced major disruptions during 2020 (COVID-19 demand collapse, negative crude oil prices) that potentially altered baseline relationships entering the Ukraine crisis. Robustness checks excluding 2020 data produce qualitatively similar GARCH parameters but with slightly reduced precision, suggesting this limitation does not fundamentally invalidate conclusions (Lütkepohl, 2005).

Second, the VAR analysis employs relatively short lag structures ($p = 2$) determined by information criteria. While diagnostic tests confirm adequate specification, longer lag structures would more comprehensively capture delayed transmission channels. The inclusion of additional macroeconomic variables (commodity prices, sentiment indices) could refine identification of shock propagation mechanisms. Monthly inflation data limitations (60 observations) versus daily financial data (1,261 observations) create asymmetries in inferential precision across dependent variables.

Third, the panel regression utilizes time-invariant energy dependence measures, imperfectly capturing shifting import sources and strategic reserve accumulation. Turkey, for instance, increased liquefied natural gas imports dramatically post-invasion, reducing structural dependence not fully reflected in annual energy import ratios. Dynamic panel estimators (Arellano-Bond, Blundell-Bond) accounting for lagged dependent variables could improve efficiency, though baseline fixed-effects estimators prove robust to serial correlation tests (Parkinson, 1980).

Fourth, the analysis focuses on linear transmission mechanisms, potentially underestimating crisis impacts during extreme market dislocations. Threshold or regime-switching specifications might

reveal nonlinear effects whereby marginal volatility increases trigger disproportionate financial instability during periods of elevated stress. The Student-t distribution employed in GARCH estimation partially addresses tail risk but cannot fully capture extreme event dynamics (Jarque-Bera rejections confirm residual non-normality).

4.7.Theoretical Contributions

This study extends multiple strands of international energy economics and emerging market finance literature. From the volatility modeling perspective, the identification of permanent regime shifts in gas market volatility dynamics complements recent work on cryptocurrency and commodity price regimes while providing energy-sector specific evidence of crisis-induced structural breaks (Bollerslev, 1986). The amplification coefficient (δ=0.1567δ=0.1567) documenting 170% greater shock response post-invasion contributes quantitative evidence to theoretical frameworks positing that geopolitical uncertainty alters market microstructure and risk premia (Engle, 1982).

The VAR-based spillover analysis expands the energy economics literature documenting international transmission channels. While prior research has established oil price pass-through to emerging markets, the specific documentation of natural gas transmission through equity, currency, and inflation channels provides granular insight into energy commodity shock propagation. The finding of unidirectional Granger causality—European gas to emerging markets, but not vice versa—clarifies the directionality of shocks and validates treating gas prices as exogenous to EME financial conditions, a critical assumption for causal inference (Granger, 1969).

The heterogeneity analysis revealing energy-dependence amplification effects (β2β2 terms statistically significant across equity, currency, and inflation specifications) provides quantitative support for vulnerability frameworks in development economics. The magnitudes—ranging from 2x to 3x main effects depending on specification—suggest that one-size-fits-all macroeconomic policy prescriptions prove inadequate when emerging markets face heterogeneous external shocks. Policymakers in energy-dependent economies require tailored responses accounting for sector-specific vulnerabilities.

5. Conclusions

This econometric analysis of European natural gas spot market dynamics and spillover to emerging market economies establishes four principal conclusions with substantial implications for international energy security, financial stability, and economic development.

5.1.Main Findings

First, Russia's invasion of Ukraine induced a fundamental regime shift in European natural gas volatility characterized by permanently elevated baseline volatility and substantially amplified shock responses. The GARCH(1,1)-X estimation demonstrates statistically significant upward level shift (γ=0.0012γ=0.0012, $p < 0.001$) and shock amplification (δ=0.1567δ=0.1567, $p = 0.002$) with 170% greater volatility response to identical-magnitude price movements post-invasion. The persistence measure (α+β=0.9777$\alpha+\beta$=0.9777) indicates that this regime change reflects structural rather than transient characteristics, with volatility shocks exhibiting 31-day half-lives compared to faster mean reversion in pre-crisis periods. This persistence persisted through 2024, establishing that gas market normalization remains incomplete despite partial supply source diversification toward liquefied natural gas.

Second, European natural gas volatility transmits significantly to emerging market financial and macroeconomic variables through multiple channels operating at distinct temporal horizons. Granger causality tests confirm unidirectional causation from gas prices to emerging market equity returns ($F = 8.34$, $p < 0.001$), exchange rates ($F = 5.67$, $p = 0.004$), and inflation ($F = 3.45$, $p = 0.034$). The impulse response functions quantify economically meaningful transmission magnitudes: a one-standard-deviation gas price shock generates peak equity market declines of -0.82 percentage points (day 3), exchange rate depreciation of -0.54 percentage points (day 5), and gradual inflation increases reaching +0.18 percentage points (day 15). The variance decomposition demonstrates that gas shocks, while explaining minimal variance at 1-day horizons, account for 18.7% of emerging market equity return variance at 20-day horizons, confirming that financial market transmission occurs gradually rather than instantaneously.

Third, emerging market vulnerability to gas price volatility exhibits substantial heterogeneity correlated with energy import dependence. The panel regression interaction coefficients document that countries with energy imports constituting 10% of GDP experience approximately 2.97 times larger equity market impacts compared to those with 5% dependence. Sub-group analysis reveals 2.19-fold greater impacts in European emerging markets (Poland, Czech Republic, Hungary, Turkey) compared to non-European economies, reflecting geographic proximity, pipeline dependencies, and deeper EU trade integration. Exchange rate and inflation channels exhibit similar heterogeneity patterns, with energy-dependent economies facing cumulative real income effects through simultaneous currency depreciation, inflation acceleration, and equity wealth losses. These findings suggest that structural vulnerability positions, not merely financial market volatility, determine emerging market crisis exposure.

Fourth, the persistent elevation of European natural gas volatility through 2024—exceeding 7.8%, more than double pre-crisis levels—establishes that energy market structural changes prove durable despite partial supply reorientation. European infrastructure constraints limiting liquefied natural gas import expansion, continued geopolitical tensions precluding Russian supply normalization, and strategic reserve accumulation requirements maintain elevated baseline uncertainty. These conditions create sustained macroeconomic challenges for emerging market policymakers managing simultaneous inflation, current account, and foreign exchange pressures. The absence of apparent mean reversion toward pre-crisis volatility levels through the end of 2024 indicates that our econometric findings capture genuinely structural—rather than cyclical—market regime changes.

5.2.Policy Recommendations

The findings generate specific policy recommendations for three constituencies: emerging market policymakers, international financial institutions, and developed economy energy policymakers.

For emerging market central banks, the identified transmission mechanisms underscore the necessity for coordinated monetary-fiscal policy frameworks accounting for commodity shock exposure. Standard inflation-targeting frameworks assuming exogenous commodity prices prove inadequate when energy volatility generates simultaneously pressures toward currency depreciation, inflation acceleration, and equity market instability. Forward guidance must explicitly incorporate energy price scenarios; stress tests should evaluate portfolio shock transmission under high-volatility energy regimes. Reserve adequacy standards require reassessment for emerging markets with substantial energy import dependence, with central banks potentially maintaining elevated foreign exchange buffers to defend currencies during energy crisis periods.

For international financial institutions (IMF, World Bank, regional development banks), the heterogeneous vulnerability findings suggest that lending facilities and technical assistance should differentiate between energy-dependent and energy-independent emerging markets. Emergency financing facilities for balance-of-payments crises triggered by commodity shocks might incorporate explicit energy price adjustment clauses, permitting programmatic relief when gas or oil prices exceed specified thresholds. Capacity building in energy market hedging strategies would enhance emerging market ability to insulate real economies from volatility, though hedging costs themselves prove substantial for fiscally constrained economies.

For developed economy policymakers in Europe and North America, the analysis highlights that energy security constitutes a fundamental international economic policy pillar with implications extending far beyond energy sectors. European natural gas market stability influences emerging market financial stability, inflation trajectories, and current account dynamics globally. Accelerated European liquefied natural gas terminal construction, investment in renewable energy infrastructure reducing gas dependence, and negotiated settlements reducing geopolitical tensions represent investments in global financial stability, not merely regional energy security. European energy policy that minimizes volatility spillovers to emerging markets generates positive externalities supporting global development objectives.

5.3.Future Research Directions

Several extensions of this analysis merit investigation. First, higher-frequency data (hourly natural gas futures, intraday spot transactions) would permit more precise identification of microstructure dynamics and shock propagation channels. Second, network analysis mapping direct and indirect energy trade linkages between European and emerging markets would clarify vulnerability channels beyond those captured by aggregate energy import intensity measures. Third, incorporating renewable energy penetration dynamics and carbon pricing mechanisms would assess whether energy transition trajectories alter long-run volatility regimes and emerging market exposure. Fourth, extending the sample period post-2024 will clarify whether elevated gas volatility persists or reverts toward historical norms, distinguishing transient crisis effects from structural regime changes.

5.4.Concluding Remarks

This study establishes that Russia's invasion of Ukraine induced fundamental restructuring of European natural gas markets transmitting substantially to emerging economy financial stability through multiple interconnected channels. The econometric evidence documents persistent volatility elevation, substantial amplification of shock responses, and heterogeneous impacts correlated with energy dependence. These findings underscore that international energy security constitutes a critical determinant of emerging market macroeconomic stability, warranting integrated policy coordination across energy, monetary, and financial stability domains. Future research should investigate whether energy transition pathways reduce such vulnerabilities or generate new transmission channels requiring policy adaptation.

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