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Price Transmission Dynamics between Natural Gas and Urea: A Global Analysis Using Cointegration and VECM Approach

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Abstract. This study examines the price transmission dynamics between natural gas and urea on a global scale over the period from 2015 to 2024, using monthly data. Recognizing urea's critical role in agriculture and its susceptibility to input cost fluctuations, we employ Johansen cointegration tests and a Vector Error Correction Model (VECM) to analyze their relationship. Our findings reveal a long-run cointegration between natural gas and urea prices, characterized by an asymmetric transmission. Specifically, natural gas prices significantly influence urea prices, but not vice versa. The study provides empirical insights that can inform policymakers and stakeholders in developing risk mitigation strategies for fertilizer price stability amid fluctuating energy markets. Moreover, the adjustment to a shock in natural gas prices on urea prices occurs with an estimated lag of approximately five months. These results underscore the vulnerability of agricultural input markets to energy price volatility, highlighting the importance of monitoring energy markets to anticipate movements in fertilizer costs.

Key words: price transmission, cointegration, VECM, energy-agriculture link, asymmetric price response.

Introduction

The role of urea in the agricultural sector is important, particularly regarding its influence on food prices. Urea, as a nitrogen fertilizer, is crucial for enhancing crop yields and, subsequently, food production. However, fluctuations in urea prices significantly impact agricultural input costs and, in turn, food prices. The recent global fertilizer crisis, influenced by various factors including geopolitical conflicts, supply chain disruptions, and rising input costs, illustrates this relationship acutely. For instance, economies that depend heavily on inputs like urea for staple

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crops may see a direct correlation between urea price fluctuations and food commodity prices. Research highlighted that during the 2008 economic crisis, food prices doubled due to similar underlying agricultural input price increases, a trend that is echoing in the current context [1].

Literature review

Recent studies indicate that urea prices can exhibit periods of stability; however, they are also subject to volatility based on external factors, particularly in the Indian maize market, where fluctuations in fertilizer prices correlate directly with changes in crop prices [2]. As Tyagi highlights, this direct correlation underscores the linkage between fertilizer input costs and agricultural outputs.

Moreover, the cost of urea is influenced by the broader dynamics of fossil fuel prices. Approximately 8% of global food demand relies on ammonia derived from natural gas, establishing a connection between rising fossil fuel costs and fertilizer prices [3]. Current geopolitical tensions and market instabilities, such as conflicts affecting oil and gas supplies, significantly impact the costs of agricultural inputs, including urea, which may subsequently affect food prices [4].

The price of natural gas plays a crucial role in determining the price of urea, a key ingredient in nitrogenous fertilizers. The production of urea is heavily reliant on natural gas, which generally accounts for approximately 70% to 80% of the total expenses associated with urea manufacturing [5]. Therefore, fluctuations in natural gas prices can have direct implications for urea pricing.

Sanyal et al. highlight that increased energy prices, including natural gas, were a significant factor leading to high fertilizer prices following the 2007-2008 crisis [6]. The volatility in natural gas prices has been shown to drive costs higher in the agricultural sector beyond just the immediate raw material costs [7]. This phenomenon emphasizes the intertwined nature of energy costs with agricultural outputs, highlighting the vulnerability this sector faces because of dependence on fossil fuels [8].

Moreover, the complex relationship between natural gas, urea, and other agricultural commodities such as corn has been explored by Yang et al., who found significant statistical interactions among these markets [9]. Their findings indicate that as natural gas prices fluctuate, they tend to affect urea prices, which in turn impact the prices of crops reliant on such fertilizers, thereby indicating a multilevel impact stemming from energy costs.

Methodology

To evaluate the direct influence on price change for Natural Gas on the price of Urea, the following tests will be applied:

Dickey-Fuller test for variables in levels and first difference – to evaluate data quality

Johansen Cointegration test – confirm that cointegration really exists

Vector Error Correction Model – evaluate the type of cointegration

The VECM takes following form (Labys, 2017):

$$\Delta X_t = \eta + \Pi X_{t-1} + \sum_{s=1}^p C_s \Delta X_{t-s} + u_t$$

Where:

ΔX_t shows the first difference of the vector X_t

η is a constant term.

ΠX_{t-1} shows the long-run relationships among the variables in the vector X_t

C_s are coefficient matrices for lagged differences (short-run dynamics) of the vector X_t and $C_s=0$ for $s>p$

u_t is the error term

X_t is a $k \times 1$ vector of variables that are integrated of order 1, denoted $I(1)$

Π is a matrix that shows the long-run relationships between the variables

We transformed formulas for Gas-Urea VECM as following

$$\Delta Urea_t = \sigma + \sum_{i=1}^{k-1} \beta_i \Delta Urea_{t-i} + \sum_{i=1}^{k-1} \varphi_i \Delta Gas_{t-j} + \gamma_1 ECT_{t-1} + \mu_{1t}$$

$$\Delta Gas_t = \alpha + \sum_{i=1}^{k-1} \beta_i \Delta Gas_{t-i} + \sum_{i=1}^{k-1} \varphi_i \Delta Urea_{t-j} + \gamma_2 ECT_{t-1} + \mu_{2t}$$

Where

– $k-1$ – the lag length is reduced by 1

– β_i, φ_j – short-run dynamic coefficients of the model's adjustment long-run equilibrium

– γ_i – speed of adjustment parameter with a negative sign

– ECT_{t-1} – the error correction term is the lagged value of the residuals obtained from the cointegrating regression of the dependent variable on the regressors. Contains long-run information derived from the long-run cointegrating relationship.

– μ_{it} – residuals (stochastic error terms often called impulses, or innovations, or shocks)

The current market situation for urea has been significantly influenced by various factors, including the rising costs of inputs, particularly natural gas, geopolitical events, and fluctuations in agricultural demand. In 2023, urea prices reflect a considerable increase compared to historical trends, with an average price reported around USD 411.38 per metric ton, marking notable fluctuations over time, from a low of USD 16 in 1971 to as high as USD 925 in April 2022 (Reid et al., 2024). This volatility underscores the challenges faced by both producers and consumers in navigating fertilizer markets.

The Asia-Pacific region is the largest producer of urea, accounting for nearly 65% of the total global production. Countries like China and India dominate this sector due to their large-scale agricultural activities and favorable policies towards fertilizer production.

North America – Urea production in North America primarily occurs in the United States and Canada, where the agricultural sector heavily relies on nitrogen fertilizers. The U.S. is making

strides in producing more urea to reduce dependence on imports, particularly from volatile markets (Swify et al., 2023).

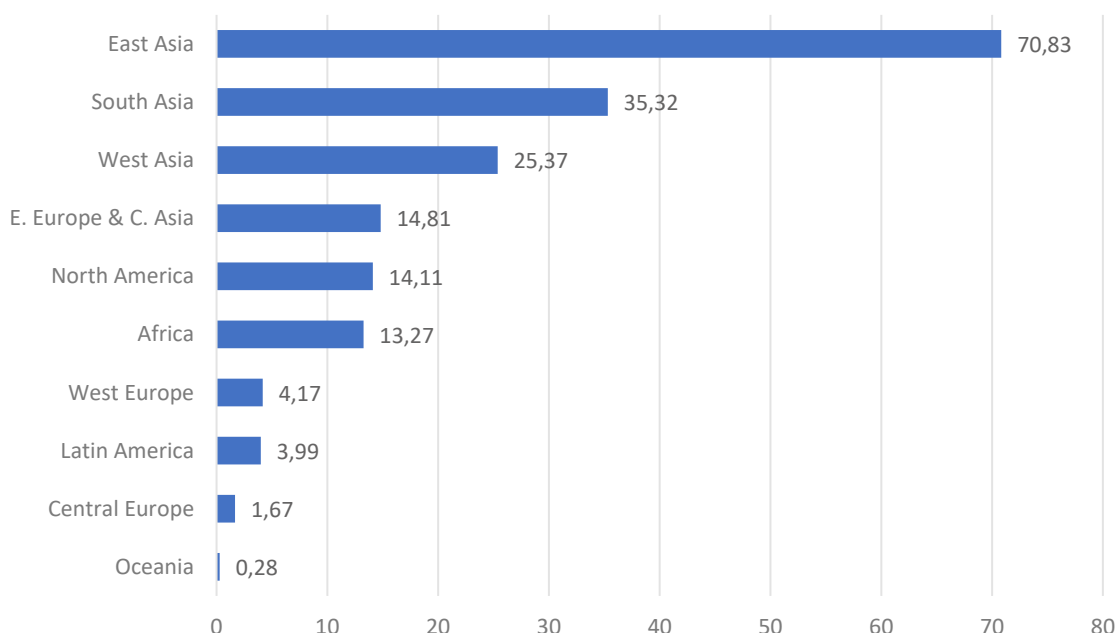


Figure 1 Production of urea worldwide in 2022, by region (in million metric tons)

Source: (Statista, 2024a) own calculations

The EU is encouraging alternative nitrogen sources to reduce the environmental impact associated with conventional fertilizers, leading to slower growth rates in traditional urea production.

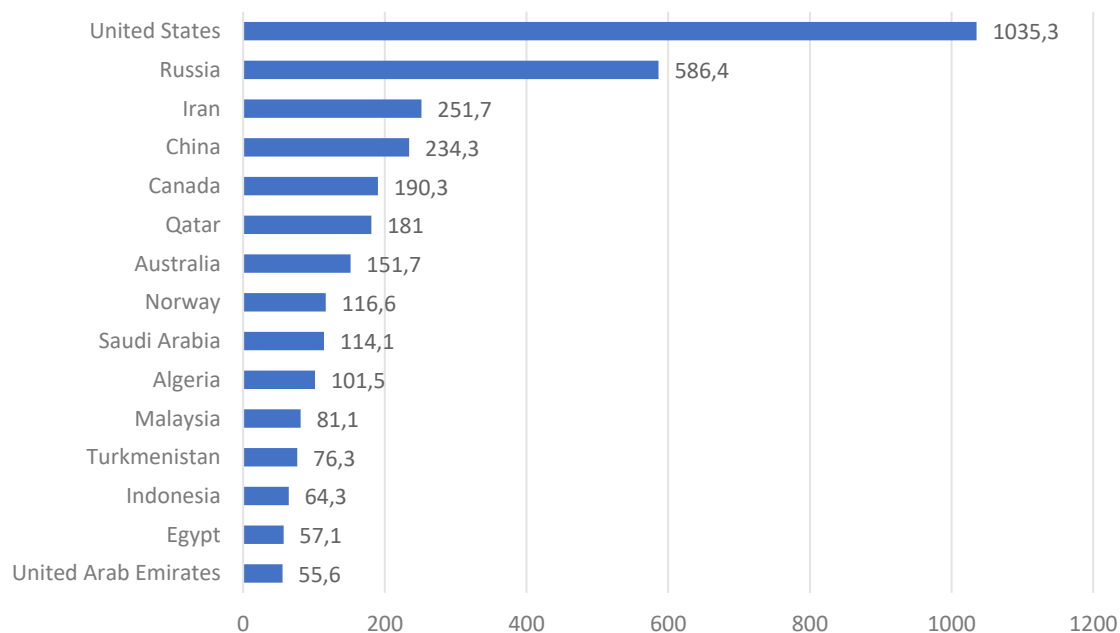


Figure 2 Production of natural gas worldwide in 2023, by country (in billion cubic meters)

Source: (Statista, 2024b) own calculations

United States: The United States remains the largest producer of natural gas globally, with an output of approximately 1,035 bcm in 2023. This production is primarily driven by the extensive development of shale gas resources through hydraulic fracturing and horizontal drilling techniques, particularly in regions such as Texas, Pennsylvania, and Louisiana.

Russia: Historically a powerhouse in natural gas production, Russia's output is around 586.4 bcm in 2023.

Iran: Iran's production is 251 bcm in 2023. While it possesses substantial natural gas reserves, Iran's ability to capitalize on these resources is limited by international sanctions and infrastructural challenges.

China: China's natural gas production is 234bcm in 2023. This includes both domestic production and plans to increase imports to meet rising energy demands as the country continues to transition towards cleaner energy sources.

Canada: Produce around 1190 bcm, Canada benefits from its abundant natural gas reserves, primarily located in British Columbia and Alberta. The success of Canadian natural gas production is linked to both domestic consumption and export to the United States.

Qatar: Qatar continues to be a leading producer, particularly in liquefied natural gas (LNG), with an anticipated production of around 191 bcm in 2023. The country is investing in the expansion of its North Field gas reserves, emphasizing its long-term commitment to LNG markets.

Australia: With a production of 151 bcm, Australia maintains its role as a significant LNG exporter, with production largely reliant on its extensive shale and coal-seam gas resources.

The natural gas production landscape in 2023 reveals a complex interplay of geopolitical factors, economic strategies, and technological advancements. The significant output from major producers like the United States, Russia, and Qatar showcases the ongoing importance of natural gas in the global energy mix.

Data used: The data used for the analysis were obtained from the Index Mundi website (Index Mundi, 2024) for the period March 2015 - January 2024, 9 years in total. The data are presented monthly and contain 107 observations.

Results and discussion

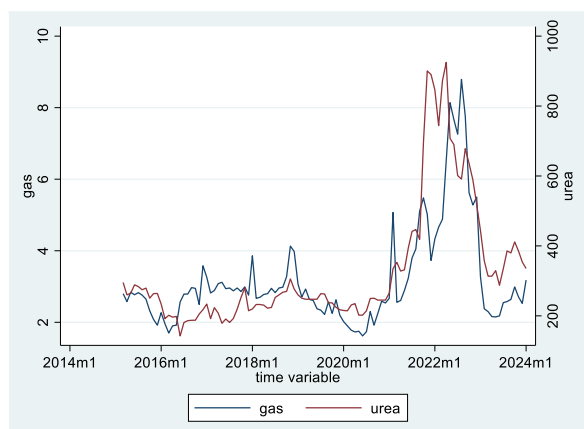


Figure 3 Price dynamics for urea and natural gas prices, March 2015 - Jan 2024

Source: own calculations

Notes: urea – price of urea (US Dollars per Metric Ton), gas- price of gas (US Dollars per Million Metric British Thermal Unit)

The graph shows the time series of natural gas prices (left y-axis) and urea prices (right y-axis) from early 2015 to early 2024, using monthly data.

From 2015 to around mid-2020, both natural gas and urea prices were relatively stable with moderate fluctuations. Natural gas prices remained mostly between 2–4 USD/MMBtu, while urea stayed between 200-300 USD/ton. Starting from late 2020, a gradual rise in both natural gas and urea prices has been observed. This period aligns with post-COVID recovery phases, where global energy and commodity demands surged.

There is a sharp increase in both natural gas and urea prices around 2021–2022. This period corresponds to major geopolitical tensions, especially the Russia-Ukraine conflict, which disrupted global natural gas supplies and, in turn, drove up fertilizer production costs.

Notably, natural gas prices spike first, and after a short delay, urea prices also surge

According to the graph results, it is possible to expect cointegration, but additional tests are required.

Table 1: Dataset description

Variable	Obs	Mean	Std, dev,	Min	Max
gas	107	3.176075	1.417922	1.62	8.79
urea	107	328.3872	179.0591	142.63	925

Source: own calculations

Natural Gas Price (US Dollars per Million Metric British Thermal Unit) and Urea Price (US Dollars per Metric Ton)

Table 2: Dickey-Fuller test for stationarity

P-value	Variable level	First difference
Urea	0.5279	0,0000
Natural gas	0.1316	0,0000

Source: own calculation

To assess the stationarity of the variables, the Augmented Dickey-Fuller (ADF) test was applied to both the urea and natural gas price series. The results show that at the level form, the p-values for urea (0.5279) and natural gas (0.1316) are greater than 0.05, indicating that both series are non-stationary in levels. However, after taking the first difference, the p-values for both variables become 0.0000, which is below the 5% significance level. This confirms that both urea and natural gas prices are stationary after first differencing. These results justify proceeding with cointegration analysis.

Table 3: Johansen cointegration test

Trend: Constant		Number of obs = 105			
Sample: 2015m5 thru 2024m1		Number of lags = 2			
Maximum rank	Params	LL	Eigenvalue	Trace statistic	Critical value 5%
0	6	-664.67878	.	21.7318	15.41
1	9	-655.43863	0.16138	3.2515*	3.76
2	10	-653.81289	0.03049		

Source: own calculations

Note: The asterisks denote selected rank

The Johansen cointegration test was conducted with a constant trend and a lag length of two. The trace statistic rejects the null hypothesis of no cointegration at the 5% significance level ($21.7318 > 15.41$), while it does not reject the null for one cointegrating relationship ($3.2515 < 3.76$). These results indicate the existence of one cointegrating vector between natural gas and urea prices, confirming a long-run equilibrium relationship between the two variables.

Table 4 Optimal lag length

Lag	LL	LR	df	p	AIC	HQIC	SBIC
0	-823.603				16.0311	16.0518	16.0823
1	-649.954	347.3	4	0.000	12.737	12.7991	12.8904*
2	-643.221	13.464	4	0.009	12.6839	12.7875*	12.9397
3	-642.029	2.3857	4	0.665	12.7384	12.8835	13.0965
4	-634.96	14.137*	4	0.007	12.6788*	12.8653	13.1393
AIC (Akaike Information Criterion), HQIC (Hannan-Quinn Information Criterion), SBIC (Schwarz Bayesian Information Criterion)							

Source: own calculations

Note: The asterisks indicate the best values

To determine the appropriate lag length for the Vector Error Correction Model (VECM), several information criteria were considered, including the Akaike Information Criterion (AIC), the Hannan-Quinn Information Criterion (HQIC), and the Schwarz Bayesian Information Criterion (SBIC). Based on the results, the minimum values of the AIC and HQIC suggest selecting a lag length of 2, while the SBIC suggests a lag length of 1. Given the trade-off between model complexity and goodness of fit, and following common econometric practice prioritizing AIC and HQIC in small samples, a lag length of two was chosen for the VECM specification.

Table 5 Estimation of the Vector Error Correction model for Gas-Urea

Cointegrating equation		
Urea	1	
Gas	-140.3817	
Constant	105.4281	
Error correction		
Dependent variable	Gas price equation	Urea price equation
ECT	-0.0512217 (0.191)	0.0019051 *** (0.0000)
$\Delta PG_t - 1$	0.2160462 *** (0.026)	-0.0018902 (0.113)
$\Delta PU_t - 1$	13.04166 (0.104)	0.0780356* (0.428)
Constant	0.0011306 *** (0.0000)	.0303978 (0.619)

Source: own calculations

Notes: Numbers in parentheses are standard errors. ** denotes statistical significance at the 5% level.

The Vector Error Correction Model (VECM) estimates the relationship between natural gas prices and urea prices over time, focusing on both long-run equilibrium and short-run dynamics. The cointegrating equation shows the long-term relationship:

$$\text{Urea} = 140.3817 \times \text{Gas} + 105.4281$$

This indicates that urea prices are positively associated with natural gas prices over the long run. As natural gas prices rise, urea prices tend to rise accordingly.

The Vector Error Correction Model (VECM) results confirm the existence of a long-run equilibrium relationship between natural gas and urea prices. The cointegrating equation indicates a strong positive long-term association, where increases in natural gas prices are linked to corresponding increases in urea prices.

The error correction term (ECT) is statistically significant only in the urea price equation, suggesting that urea prices adjust to correct deviations from the long-run equilibrium, whereas natural gas prices do not. This asymmetry implies that natural gas prices act as a driver of urea prices, but not vice versa. In the short run, the gas price equation shows that current gas prices are significantly influenced by their own past values, while past urea price changes have no significant effect. Conversely, urea price dynamics exhibit only weak short-run dependence on their own past changes and are not immediately responsive to short-term fluctuations in natural gas prices.

Overall, the findings highlight a unidirectional and lagged transmission mechanism from natural gas to urea prices, aligning with the broader understanding of energy inputs as critical determinants of fertilizer costs.

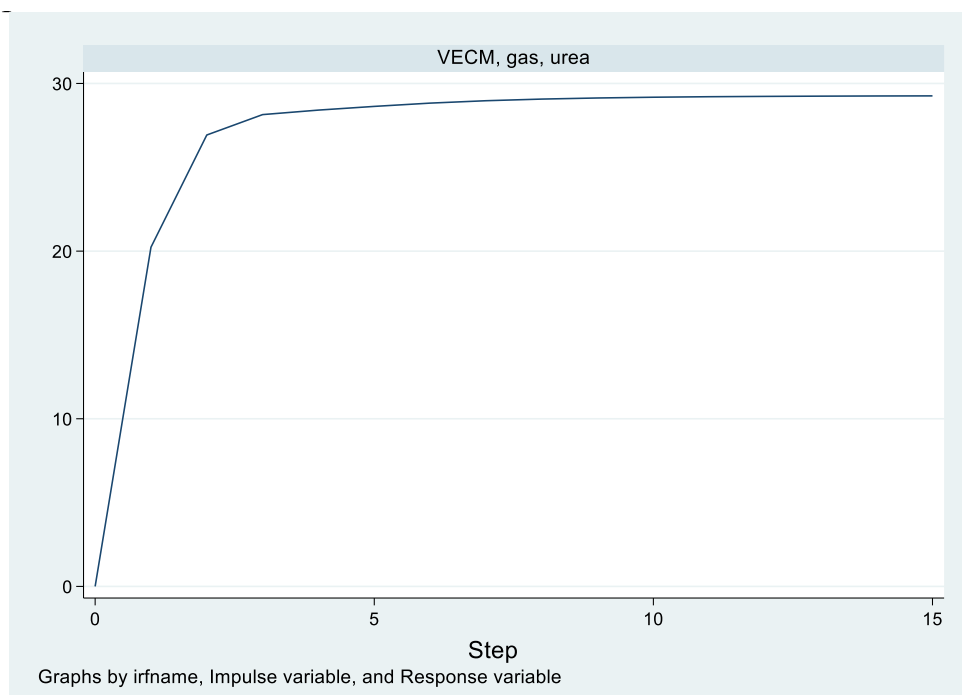


Figure 4 Impulse responses for a one standard deviation shock price

Source: own calculations

We can see a 5-month reaction to the shock price of gas for urea.

The results of the cointegration analysis for Urea and Natural gas prices during March 2015-January 2024 monthly showed the following:

1. The Dickey-Fuller test shows non-stationarity in levels and stationarity in first differences for both variables.

2. The Johansen Cointegration test showed cointegration between Urea and Natural gas prices.

3. Results of the VECM model revealed:

- Exists long-run relationship exists between Urea and Gas.
- However, only Gas is affected by Urea, but the price of Urea does not have any effect on Gas.

Price transmission is asymmetric. In a short period to urea prices affected the previous period's urea prices, and gas prices affected the previous period's gas prices.

- The reaction time lag is approximately 5 months for Urea to shock price in Gas.

Conclusion

Given urea's fundamental role as a primary nitrogen fertilizer essential for global food production, fluctuations in urea prices can have significant downstream impacts on agricultural costs and food prices. Therefore, understanding the relationship between energy markets and fertilizer prices is critical for policymakers, farmers, and food industry stakeholders to better manage risks and ensure stable food supply chains in a volatile global environment.

This study investigated the long-term and short-term dynamics between natural gas and urea prices from March 2015 to January 2024, using monthly data. The Dickey-Fuller tests

confirmed that both series are non-stationary in levels but stationary in first differences, enabling the application of Johansen cointegration analysis. The results indicate the existence of a long-run cointegration relationship between natural gas and urea prices. The VECM analysis further revealed that price transmission is asymmetric: natural gas prices influence urea prices, but not the other way around. Short-term dynamics showed that each variable's past values predominantly affect their own future values. Importantly, we identified a five-month lag in the response of urea prices to shocks in natural gas prices.

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Прагадағы Чехия ауыл шаруашылығы ғылымдары университеті, Прага, Чехия

**Табиғи газ бен карбамид арасындағы баға беру динамикасы: коинтеграция
және VECM әдістері негізінде жаһандық талдау**

Аңдатпа. Бұл зерттеуде 2015–2024 жылдар аралығындағы ай сайынғы деректер негізінде табиғи газ бен карбамид (мочевина) арасындағы баға беру динамикасы жаһандық деңгейде қарастырылады. Карбамидтің ауыл шаруашылығындағы маңыздылығын және оның шикізат бағасының ауытқуына бейімділігін ескере отырып, зерттеуде Йохансен коинтеграция тесттері мен VECM (векторлық қателік түзету моделі) әдісі қолданылды. Нәтижелер табиғи газ бен карбамид бағалары арасында ұзақ мерзімді коинтеграциялық байланыс бар екенін көрсетеді, бұл байланыс асимметриялы сипатқа ие. Яғни, табиғи газ бағасы карбамид бағасына айтарлықтай әсер етеді, ал кері әсер байқалмайды. Сонымен қатар, табиғи газ бағасының өзгерісі карбамид бағасына шамамен бес айлық кідіріс арқылы әсер етеді. Бұл нәтижелер ауыл шаруашылығы саласының энергетикалық нарықтағы баға тұрақсыздығына осал екенін көрсетіп, тыңайтқыш бағасының өзгерістерін болжау үшін энергетикалық нарықты тұрақты бақылау қажеттігін айқындайды.

Түйін сөздер: баға трансмиссиясы, коинтеграция, векторлық қателік түзеу моделі (VECM), энергия мен ауыл шаруашылығы арасындағы байланыс, асимметриялық баға әсері.

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**Динамика передачи цен между природным газом и карбамидом: глобальный анализ
с использованием коинтеграции и модели VECM**

Аннотация. В данном исследовании рассматривается динамика передачи цен между природным газом и карбамидом (мочевинной) в глобальном масштабе за период с 2015 по 2024 год

на основе ежемесячных данных. Учитывая ключевую роль карбамида в сельском хозяйстве и его чувствительность к изменениям себестоимости сырья, были применены тесты коинтеграции Йохансена и векторная модель коррекции ошибок (VECM) для анализа взаимосвязи. Результаты показали наличие долгосрочной коинтеграционной связи между ценами на природный газ и карбамид с асимметричной передачей. В частности, цены на природный газ существенно влияют на цены карбамида, но не наоборот. Кроме того, реакция цен на карбамид на шок в ценах на газ происходит с задержкой примерно в пять месяцев. Полученные результаты подчеркивают уязвимость аграрного сектора к волатильности энергетических рынков и необходимость постоянного мониторинга энергорынков для прогнозирования изменений в стоимости удобрений.

Ключевые слова: ценовая передача, коинтеграция, модель векторной коррекции ошибок (VECM), взаимосвязь энергетики и сельского хозяйства, асимметричная ценовая реакция.

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