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The Surge in Indonesian Robusta Coffee Price: The Interaction of Substitute Commodity Prices and Exchange Rates on Robusta Price Behavior

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Abstract

Primary commodity price trends frequently exhibit co-movement patterns, demonstrating similar fluctuations. The surge in substitute commodity prices, such as Arabica coffee and cocoa, in both Indonesian and global markets has positively impacted the increasing price of Indonesian Robusta coffee. This study explored the factors driving the surge in Indonesian Robusta coffee price, particularly the co-movement of substitute commodity prices and exchange rates, and how these elements influence Indonesian Robusta coffee price behavior. Utilizing time series data from January 1, 2019, to December 31, 2024, the research applied the ARDL-ECM approach to estimate the cointegration relationships among the variables. The results revealed that lagged Indonesian Robusta prices, world Robusta price, Indonesian Arabica price, lagged world Arabica price, London cocoa price, and the Rupiah exchange rate significantly affected Indonesian Robusta price at the 1%, 5%, and 10% significance level, both in the long and short run. Furthermore, the study identified a bidirectional causality between Indonesian Robusta coffee price and three independent variables: New York, London, and cocoa indicator prices. In contrast, Arabica prices, rubber prices, and exchange rates showed no causality with the Indonesian Robusta coffee price. The analysis also indicated that price co-movement was only reflected among related commodities, while no such relationship was found for unrelated commodities. The upward trend in world Robusta price, Indonesian Arabica price, world Arabica price, and world cocoa prices can be interpreted as indicators of a flourishing agricultural primary commodity market, which may subsequently drive up Robusta coffee prices in the domestic market.

Keywords: Coffee, Robusta, co-movement, commodity price, autoregressive

INTRODUCTION

In today's era of trade liberalization, a country's participation in international trade is driven by the goal of generating profits and gaining benefits from the global trade system (Chacoliades, 1978). Trade liberalization provides several advantages, including easier access to a wider array of resources, enhanced competitiveness, accelerated technology transfer, increased economic growth, and improved efficiency. Additionally, it offers opportunities through varying relative prices for trading these resources. One of the key opportunities presented by trade liberalization is the potential for creating greater added value, which can enhance the welfare of society, particularly for small businesses and farmers. However, engaging in a free trade system also requires readiness to compete amidst the uncertainties of the global market. In the agricultural sector, especially within the plantation subsector, market openness can negatively impact commodity price stability due to fluctuations in supply and demand, market speculation, and other changes in the global market. This price volatility poses a significant threat to farmers and small businesses in developing countries. As commodity prices become more erratic, the influence of market forces grows stronger (Yovo & Adabe, 2022), leading to heightened competition with imported products. Consequently, producers with weak bargaining positions are more susceptible to price instability shocks in the international market.

Since implementing trade policy reforms in the 1980s, Indonesia has decisively enhanced its export activities to drive economic growth through foreign exchange earnings. These reforms have significantly bolstered the sustainability of agricultural commodity supplies, especially given that Indonesia is a key player in producing plantation export goods. Coffee is outstanding among these commodities, contributing significantly to the trade balance and solidifying Indonesia's place within the global trade value chain. While coffee is an essential export product, it is predominantly cultivated by smallholder plantations, which accounted for about 98.43% of production in 2023 (BPS, 2024). This strong involvement of smallholders underscores how coffee exports can directly elevate the welfare of farmers. Indonesia primarily cultivates two coffee varieties: Robusta and Arabica. However, the focus of most smallholder plantations is on Robusta coffee. According to the International Coffee Organization (ICO, 2023), Indonesia is the second-largest coffee producer in Asia and Oceania, only behind Vietnam, with an impressive total coffee production of around 720,000 t for the 2022/2023 season. Robusta coffee constitutes 82.5% of this production, totaling approximately 594,000 t in the same timeframe.

Coffee is Indonesia's leading export product and a vital pillar of the national economy, providing significant contributions to the agricultural sector. Research by Murindahabi *et al.* (2019) demonstrated a strong positive correlation between coffee exports and the country's average GDP. A one percent increase in coffee exports is associated with a 0.0217% rise in average GDP, based on comprehensive data from 32 coffee-exporting countries. In Indonesia, coffee exports have consistently accounted for an impressive average contribution of 3.13% annually to GDP growth in the plantation sector from 2011 to 2020 (Suwali *et al*., 2022). Looking ahead to 2023, Indonesia's total coffee exports are estimated to hit 280 thousand tons. Staying true to its production dynamics, Robusta coffee dominates the export market, making up 78.78% of total exports; meanwhile, Arabica coffee contributes 18.50%, and the remaining 1.40% is attributed to other coffee products (BPS, 2024). This pivotal role of coffee in the economic landscape reaffirms its significance, not merely as a beverage commodity but as a key driver that significantly enhances producer welfare and bolsters the global economy.

Indonesian coffee, including Robusta and Arabica varieties, is significantly influenced by international market volatility and substantial price fluctuations. As an inelastic commodity, coffee's pricing behavior presents challenges in predictability (Gajdušková, 2020), and this volatility has crucial implications for Indonesia's economy as both an exporter and importer (Lubis & Lubis, 2024); furthermore, commodities—particularly raw materials or primary products—often exhibit price co-movement, a trend applicable to coffee. Research by Pindyck and Rotemberg (1990) highlighted the price co-movements of various commodities such as wheat, cotton, and crude oil. They revealed that the advantage of co-movement lies in the presence of correlation among unrelated commodities, which traditional macroeconomic factors, including inflation, interest rates, exchange rates, or changes in aggregate demand, cannot easily be explained. In contrast, Ai *et al.* (2006) argued that co-movements are mainly seen in related commodities, indicating that this phenomenon did not apply to unrelated ones. This difference in findings underscores the complexity of commodity pricing dynamics and the need for further research.

Signals of this co-movement are reflected in the significant price increases of various commodities on the international market, particularly during the early 2000s. Traore & Badolo (2016) reported that cocoa prices surged over 200%, doubling between January 2005 and January 2010. During the same period between January 2005 and April 2011, coffee and cotton saw impressive increases, tripling and quadrupling, respectively. This concurrent rise in the prices of coffee and cocoa demonstrated their strong correlation as substitute commodities with similar characteristics. Looking ahead, we can expect Robusta coffee prices to rise significantly, estimated to increase by 74.75% by December 2024 compared to December 2023 (ICO, 2024). This upward trend also happens to other commodities such as Arabica coffee, cocoa, and rubber, which are experiencing simultaneous price increases in the international and Indonesian domestic markets, as shown in Figure 1. It presents evidence that fluctuations in market liquidity tend to drive commodity prices to move (upward and downward) in the same direction, reflecting the interconnected nature of commodity markets and their sensitivity to changes in overall economic conditions (Zhang *et al.*, 2019; Delle Chiaie *et al.*, 2022).

The four commodities, namely Robusta coffee, Arabica coffee, cocoa, and rubber exhibit similar characteristics that naturally lead their prices to move together along the supply side (Traore & Badolo, 2016), particularly on the primary commodity markets. While all these crops can thrive under comparable land conditions, Arabica coffee demonstrates better production outcomes in high-altitude areas. This similarity of growing land significantly influences producers' decisions about selecting crop cultivation and what commodities to produce. Producers are strategically inclined to invest in Robusta coffee when prices rise, and they are quick to pivot to other crops like cocoa or rubber when prices fall. Furthermore, in situations where both Robusta coffee and rubber present lucrative opportunities, producers can effectively grow those crops on the same land by applying an intercropping or agroforestry system (Huang *et al.*, 2023). Additionally, all four commodities are actively traded in the same markets, encompassing futures and spot markets. These interconnected circumstances make Arabica coffee, cocoa, and rubber economically viable substitutes for Robusta coffee, despite their differences in utilization and target markets. While this substitution may not always happen directly, it undoubtedly impacts economic decisions regarding optimizing land productivity, production planning, and risk management. Therefore, price volatility among these four commodities is a critical concern for Indonesia, as a major producer and exporter. It will be determinative in effectively making decisions and policies to boost production in the short and long run.

Integrating the Indonesian coffee market with the international market significantly impacts coffee prices, making them sensitive to macroeconomic factors. These macroeconomic variables such as currency exchange rates, inflation, demand, and interest rates play a vital role in determining price expecta-

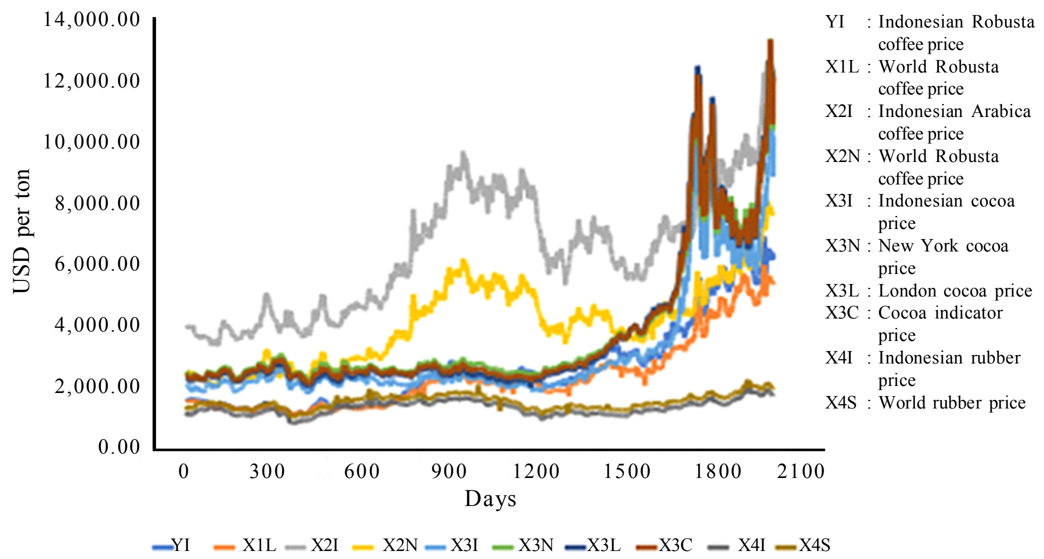

Figure 1. Daily price movement of Robusta and other substitute commodities from January 2019 to December 2024

tions, particularly for farmers and producers. Currency exchange rates are directly correlated with commodity price movements (Kisswani *et al.*, 2025). For example, fluctuations in the Rupiah's value against other currencies can immediately affect coffee prices in the Indonesian spot market, especially in the short term. It reflects an ongoing exchange of market information and deepens in market connectivity (Anand K. & Mishra, 2024). The exchange rate of the US dollar can exert a sustained influence on agricultural commodity prices, primarily because global trade is predominantly denominated in US dollars, and most commodities, including coffee, are quoted and transacted in this currency (Vatsa, 2022). Consequently, when the Rupiah weakens against the US dollar (Rupiah devaluation), it may boost export revenues and better prices for farmers. However, a depreciation in the Rupiah's value can also negatively impact production costs for producers (Lubis & Lubis, 2024). This dual effect highlights the complexities associated with the influence of exchange rates on the coffee value chain.

Research on how commodity prices move together has been studied for over 30 years, particularly in identifying how related and unrelated commodity prices affect each other. This topic has been carried out using various methodologies, commodity modeling, and varied commodities. Pindyck & Rotemberg (1990) were among the first to explore price movements in commodities that happen simultaneously but were not associated with common factors. Many other studies, such as those by Deb *et al.* (1996), Ai *et al.* (2006), Traore & Badolo (2016), Le Pen & Sévi (2018), Cai *et al.* (2020), and others have built on their work related to this theory. This study explored the factors driving the surge in Indonesian Robusta coffee prices, particularly the co-movement of substitute commodity prices and exchange rates, and how these elements influence Indonesian Robusta coffee price behavior.

A related study by Alquist *et al.* (2020) analyzed price co-movements in 40 commodities using macroeconomic models. These were divided into 22 food commodities, 5 oil commodities, and 13 industrial commodities. Kozian *et al*. (2025) also explored various methods, such as VAR, VARX, Multiple Regression, Random Forest Regression, Pearson Correlation, and Gerber Statistic, to study price co-movements in 20 commodities alongside macroeconomic parameters. Their study included supply and demand determinants, interest rates, exchange rates, market uncertainty, and inflation. This research differs by focusing specifically on Robusta and Arabica coffee. It also considers the Rupiah to US dollar exchange rate and the prices of Robusta coffee, Arabica coffee, cocoa, and rubber in both the futures and Indonesian spot markets.

Most previous studies have focused on analyzing coffee prices in general and discussing the price co-movement in individual markets. This research takes a broader approach by investigating price co-movement among commodities across different markets. These commodities represent food and non-food-related commodities that have distinct market characteristics. Thus, it builds on the current knowledge on coffee commodities and offers valuable insights for market chains and policy-makers dealing with price changes in the global market. The findings can be considered for planning strategies for managing price risk and leading national price stabilization policies. Understanding of it assists farmers, exporters, and other market players in making better decisions about commodity investments, production strategy, and marketing.

MATERIALS AND METHOD

Data Collection

The research data consisted of two categories of series data: price for 4 commodities in different markets to evaluate the co-movement, and the exchange rate as a macroeconomic variable to explain their influence on prices. The time frame of the data ranges from January 1, 2019, to December 31, 2024. These sources included the International Coffee Organization (ICO), the International Cocoa Organization (ICCO), the Intercontinental Exchange (ICE), the Commodity Futures Trading Regulatory Authority (CFTRA), the Central Bank of Indonesia, and other secondary data.

The collected data included world Robusta coffee price (futures price in the London Futures Market), Indonesian Robusta coffee price (Lampung Spot Market), world Arabica coffee price (futures price in the New York Futures Market), Indonesian Arabica coffee price (Medan Spot Market), world cocoa prices (futures prices in New York and London, and ICCO indicator prices), Indonesian cocoa price (Makassar Spot Market), world rubber price (futures price in the Singapore Futures Market), Indonesian rubber price (Palembang Spot Market), and Indonesian Rupiahs to US dollar exchange rate. Most of this data was consistently provided for the study period, however, some data were missing due to limited trading on the Indonesian spot market. Preceding the analysis, commodity price data were converted into the same value of USD per ton. Both price data and the exchange rate were changed into natural logarithms.

Analysis Method

When analyzing time series data, it is crucial to assess the stationarity of the data to ensure accurate interpretations of the analysis results. Utilizing non-stationary data in regression analysis can lead to misleading outcomes, known as pseudo-regression, where a significant relationship appears between the dependent and independent variables, despite the absence of meaningful relationships. Data stationarity is classified into three categories based on the order of integration: stationary at the level (original data/(I(0)), first difference (I(1)), or second difference (I(2)). Each dataset may expose a different integration order, so the alternative model applied is the Autoregressive Distributed Lag (ARDL) model. This model can be modified into an Autoregressive Distributed Lag-Error Correction Model (ARDL-ECM) that investigates long-run and short-run relationships. The operation of estimating the ARDL-ECM model (Traore & Badolo, 2016; Hundie & Biratu, 2020) is explained in the following steps:

Stationarity Testing

All variables included in the ARDL model were analyzed using a unit root test to determine stationarity on each variable. The Augmented Dickey-Fuller (ADF) test was used to confirm data stationarity and the order of integration. No variables must be integrated into the second difference (I(2)), as the ARDL model is only applied to variables with integration orders of I(0) and I(1), or to variables that have an integration order of I(1).

ARDL Model Estimation

The ARDL model was estimated using the Ordinary Least Squares (OLS) method and represented in the following general equation:

$$LnYI_t = \alpha_0 + \sum_{i=1}^{p} \beta_i LnYI_{t-i} + \sum_{j=0}^{q} \gamma_j LnX_{t-j} + \epsilon_t$$

while α_0: coefficient of constant, β_i: regression coefficients of YI_{t-I}, γ_j: lag distribution coefficients of the independent variable, p: the maximum lag order of the dependent variable, q: the maximum lag order for the independent variable, and ϵ_t: error term. This equation model includes 1 dependent variable and 10 independent variables. The dependent variable is denoted as Indonesian Robusta coffee price (LnYI), while the independent variables (LnX) include world Robusta coffee price (LnX1L), Indonesian Arabica coffee price (LnX2I), world Arabica coffee price (LnX2N), Indonesian cocoa price (LnX3I), New York cocoa price (LnX3N), London cocoa price (LnX3L), cocoa indicator price (LnX3C), Indonesian rubber price (LnX4I), world rubber price (LnX4S), and exchange rate (LnX5K).

The estimation of this model revealed both long-run and short-run coefficients, enabling an in-depth understanding of the interdependence of variables. The optimal lag for the ARDL model was determined using the Akaike Information Criterion (AIC), a critical step that ensures the best number of lags for each variable.

Cointegration Testing

The ARDL model has a powerful alternative to assess long-run relationships between variables. A cointegration test was conducted using the bounds test method from Pesaran *et al. cit.* Traore & Badolo, 2016. It was confirmed if the resulting F-statistic exceeded the upper bound value (I(1)), leading to the rejection of the null hypothesis (H_0). This demonstrated a significant long-run relationship (cointegration) between the variables.

ARDL-ECM Model Estimation

Once cointegration was established, the ECM estimation was conducted. The equation of this model was represented as follows:

$$\Delta LnYI_t = a_0 + \sum_{i=1}^{p-1} \beta_i \Delta LnYI_{t-i} + + \sum_{i=1}^{p-1} \gamma_{kj} \Delta LnX_{k,t-j} + \Phi ECT_{t-1} + \epsilon_t$$

In this equation, Δ indicates the difference in the variable (first difference), and ECT represents the error correction term, which captures deviations from long-run equilibrium. A negative and significant ECT coefficient indicated adjustments toward long-run balance, ensuring that any imbalances will be corrected in subsequent periods.

Granger Causality Testing

The Granger causality test effectively identifies the causality between independent and dependent variables, particularly in time series analysis. While specific regression models may obscure these causal relationships, this approach enabled us to clarify directional or bidirectional relationships. The general equation for the Granger causality

$$\{LnYI_t = a_0 + \sum_{i=1}^{p} \alpha_i LnYI_{t-i} + \sum_{i=1}^{q} \beta_j LnX_{t-j} + \epsilon_t \; LnX_t = \gamma_0 + \sum_{i=1}^{p} \gamma_i LnYI_{t-i} + \sum_{j=1}^{q} \delta_j LnX_{t-j} + \mu_t$$

with p, q: number of selected lags; α, β, γ, δ: estimated coefficients; ϵ_t, μ_t: error term (white noise). Rejecting H_0 expressed by the p-value of the F-statistic falls below the 5% significance level. This indicates that LnYI Granger causes LnX or LnX Granger causes LnYI. By following these steps and methodologies, we can derive meaningful insights from time series data analysis.

Diagnostic Testing of the ARDL Model

A comprehensive set of diagnostic tests was rigorously applied to validate the robustness and reliability of the model. These tests included (i) the Breusch-Godfrey Test and Durbin-Watson Test to examine autocorrelation, (ii) the Breusch-Pagan-Godfrey Test and White Test to investigate heteroscedasticity, and (iii) the Jarque-Bera Test to assess the normality of residuals. The ARDL model is considered valid and reliable when it demands stringent criteria: the nonexistence of serial correlation, no heteroscedasticity, and normally distributed residuals (Gujarati & Porter, 2010; Smith & Taylor, 2017). This interpretation is crucial for composing impactful policy recommendations, especially aimed at mitigating the price volatility of Indonesian Robusta coffee, its relationships with substitute commodities, and the effects of exchange rate fluctuations.

RESULTS AND DISCUSSION

Data stationarity is a fundamental criterion for macroeconomic analysis and time series modeling, because non-stationary data can significantly skew model estimation results. The price behavior of coffee and other primary commodities often reveals trends or fluctuations, which makes their non-stationary nature highly probable. Such non-stationarity can lead to significant errors in understanding variable relationships, particularly when capturing short-run and long-run dynamic relationships. The order of integration based on the data stationarity was clearly outlined in Table 1.

Table 1 revealed that each variable has a different order of integration. Notably, the exchange rate was stationary at level (I(0)) with significance levels of 5%, and other variables were classified as stationary only at the first difference (I(1)). The difference in stationarity indicated the fitness of the ARDL method, which ultimately led to modifying it into the ARDL-ECM model.

The analysis presented in Table 2 indicated that the ARDL model, selected using the Akaike Information Criterion (AIC), was ARDL (4, 4, 0, 1, 0, 0, 0, 0, 4, 4, 1). The findings revealed that the Indonesian Robusta coffee price, as the dependent variable, had a maximum lag of 4. Whereas, the independent variables ranged from lag 0 to 4. The model emphasized a coefficient of determination (R^2) of 0.6702, demonstrating that approximately 67.02% of the Indonesian Robusta coffee prices' co-movement model was explained, with the remaining 32.98% attributed to external factors.

Furthermore, the independent variables simultaneously influenced the Indonesian Robusta coffee price, as illustrated by the F-statistic p-value clearly below the α = 5% threshold. This indicated a long-run relationship between the Indonesian Robusta coffee price, the world and Indonesian Arabica coffee prices, the world and Indonesian cocoa prices, and the world and Indonesian rubber prices, alongside the exchange rate.

The statistical results in Table 2 unequivocally pointed out that the Indonesian Robusta coffee price was significantly influenced by its past values, showing an autoregressive lag effect up to the fourth lag at a 1% significance level (p-value = 0.0000). The negative coefficient on the lagged Indonesian Robusta coffee price reflected a clear inertia or autoregressive effect, confirming that past price changes influenced current price levels and tended to suppress those levels. This finding aligned decisively with the observations of Tomek & Robinson (1972) and Tomek & Kaiser (2014), who identified that the pricing behavior of agricultural commodities in spot markets is intrinsically connected to prior price movements (time lag).

The world Robusta coffee price, extending up to the 4th lag, significantly influenced the Indonesian Robusta coffee price at a 1% significance level, shown by a p-value of 0.0000. This stated that the price of Robusta coffee

Table 1. Results of the unit root test on the variables using the Augmented Dickey-Fuller (ADF) method

Unit root test	Variable	Order of integration					
		Level			First difference		
		t-Statistic	Prob.*	H_0	t-Statistic	Prob.*	H_0
Augmented Dickey-Fuller test statistic	LnYI	-2.519331	0.3186	Accepted	-36.63023	0.0000 ***	Rejected
	LnX1L	-2.371808	0.3942	Accepted	-42.91955	0.0000 ***	Rejected
	LnX2I	-2.106090	0.5414	Accepted	-37.39963	0.0000 ***	Rejected
	LnX2N	-1.946669	0.6291	Accepted	-39.53353	0.0000 ***	Rejected
	LnX3I	-1.015025	0.9402	Accepted	-38.39417	0.0000 ***	Rejected
	LnX3N	-0.844758	0.9600	Accepted	-35.74228	0.0000 ***	Rejected
	LnX3L	-0.679190	0.9736	Accepted	-32.20412	0.0000 ***	Rejected
	LnX3C	-0.592385	0.9789	Accepted	-33.34835	0.0000 ***	Rejected
	LnX4I	-2.303876	0.4310	Accepted	-38.04176	0.0000 ***	Rejected
	LnX4S	-2.113702	0.5371	Accepted	-46.02036	0.0000 ***	Rejected
	LnX5K	-3.886215	0.0129 **	Rejected			

Notes: ***Significant at 1% level (test critical values: -3.965340)
**Significant at 5% level (test critical values: -3.413379)
* Significant at 10% level (test critical values: -3.128724)

Table 2. Results of significance parameter on the ARDL model of Indonesian Robusta coffee price

Variable	Coefficient	Std. error	t-Statistic	Prob.*
D(LnYI(-1))	-0.278462	0.028193	-9.876962	0.0000 ***
D(LnYI(-2))	-0.193122	0.028535	-6.767983	0.0000 ***
D(LnYI(-3))	-0.093611	0.028025	-3.340205	0.0009 ***
D(LnYI(-4))	-0.061122	0.025858	-2.363799	0.0182 **
D(LnX1L)	0.639785	0.019067	33.55489	0.0000 ***
D(LnX1L(-1))	0.366536	0.027711	13.22700	0.0000 ***
D(LnX1L(-2))	0.219438	0.028818	7.614543	0.0000 ***
D(LnX1L(-3))	0.127620	0.028350	4.501530	0.0000 ***
D(LnX1L(-4))	0.080384	0.025076	3.205567	0.0014 ***
D(LnX2I)	0.256556	0.038264	6.704822	0.0000 ***
D(LnX2N)	-0.035657	0.036930	-0.965542	0.3345
D(LnX2N(-1))	-0.039039	0.017915	-2.179130	0.0295 **
D(LnX3I)	0.011806	0.012095	0.976096	0.3292
D(LnX3N)	0.010585	0.055760	0.189827	0.8495
D(LnX3L)	-0.100646	0.059306	-1.697067	0.0899 *
D(LnX3C)	0.068291	0.098317	0.694606	0.4874
D(LnX4I)	-0.006499	0.029648	-0.219213	0.8265
D(LnX4I(-1))	-0.020361	0.034090	-0.597254	0.5504
D(LnX4I(-2))	0.041912	0.034787	1.204830	0.2285
D(LnX4I(-3))	-0.017254	0.033286	-0.518358	0.6043
D(LnX4I(-4))	-0.062613	0.028817	-2.172810	0.0300 **
D(LnX4S)	-0.009411	0.028384	-0.331546	0.7403
D(LnX4S(-1))	0.033621	0.035181	0.955644	0.3394
D(LnX4S(-2))	-0.054362	0.036977	-1.470169	0.1418
D(LnX4S(-3))	0.042895	0.035347	1.213564	0.2251
D(LnX4S(-4))	0.128051	0.028889	4.432584	0.0000 ***
LnX5K	-0.373576	0.076532	-4.881330	0.0000 ***
LnX5K(-1)	0.375852	0.076661	4.902773	0.0000 ***
C	-0.021653	0.072299	-0.299494	0.7646
R-squared	0.670244		Mean dependent var	0.001010
Adjusted R-squared	0.662731		S.D. dependent var	0.021100
S.E. of regression	0.012254		Akaike info criterion	-5.943150
Sum squared resid	0.184547		Schwarz criterion	-5.824723
Log likelihood	3767.241		Hannan-Quinn criterion.	-5.898643
F-statistic	89.21411		Durbin-Watson stat	2.001897
Prob(F-statistic)	0.100			

Notes: ***Significant at 1% level
**Significant at 5% level
* Significant at 10% level

in the Indonesian spot market proactively aligned with the trends of price formation on the London futures market. These results indicated a strong integrated relationship between the Indonesian and global coffee markets. Another factor exerting a statistically positive effect on the Indonesian Robusta coffee price was the Indonesian Arabica coffee price. Despite their unique characteristics, these two coffee types showed a positive correlation in their price movements. Stavrakoudis & Panagiotou (2017) found that Arabica and Robusta coffees move in tandem, showing similar patterns during price booms and slumps. While the price interdependence between these two varieties was relatively moderate, it was apparent that the probabilities of price transmission were different. Price increases were transmitted more swiftly than decreases. Research by Fousekis (2017) supported that statement, showing high co-movements in global coffee prices. The interdependence between the prices of these two coffee types showed their characteristics as the closest substitutes.

Moreover, the world Arabica coffee price does not exert a statistically significant effect on the price trends of Indonesian Robusta coffee. It is evidenced by a t-statistic probability value greater than 0.05, suggesting that world Arabica price fluctuation lacks a meaningful explanatory power concerning the domestic pricing behavior of Robusta coffee in Indonesia. The world Arabica and Indonesian Robusta coffee prices did not interlink since their trade transactions occurred in distinctive markets. Specifically, Arabica is traded in the New York futures market, while Robusta is traded on the London futures market, leading to divergent price formations. However, the lagged one-period price of the world Arabica coffee shows a statistically significant influence on the expected price of Robusta coffee in Indonesia's spot market at a 5% significance level. This indicates that historical changes in international Arabica prices may serve as a predictive indicator, shaping market expectations and influencing short-term pricing behavior of Robusta coffee at the domestic level.

Considering cocoa as the closest substitute for coffee does not necessarily have a direct influence on the price behavior of Indonesian Robusta coffee in either domestic or international markets. The empirical analysis clearly showed that Indonesian Robusta prices generally remain unaffected by domestic or world cocoa prices. The only exception is the cocoa price on the London futures market, which has a p-value of 0.0899 below the 10% significance level. It indicates a weak relationship, however, statistically significant in influencing market price movement. This limited influence is likely due to the structural similarities in the trading of Robusta coffee and cocoa, particularly within the London futures market, where both commodities are actively traded. This connection suggests that substitution effects do not drive price co-movements, but rather by shared market mechanisms or overlapping speculative behavior within the same trading platform.

The other related commodities, such as Indonesian and world rubber prices, did not statistically have an impact on the Indonesian Robusta coffee prices in general. The first to third lags of changes in domestic rubber prices (D(LnX4I(-1)), D(LnX4I(-2)), D(LnX4I(-3))) exhibit statistically insignificant coefficients, as indicated by p-values exceeding the 5% threshold. This suggests that short-term fluctuations in domestic rubber prices, within a one- to three-day period, do not exert a statistically meaningful influence on Robusta coffee prices in the Indonesian spot market.

In contrast, the fourth lag (D(LnX4I(-4))) presents a negative and statistically significant coefficient (-0.062613) with a p-value of 0.0300, indicating a significant impact at the 5% level. This finding implies that changes in domestic rubber prices four days prior are inversely linked to current Robusta coffee prices. Although the magnitude of the effect is relatively modest, it suggests a delayed response in market reallocation, where an increase in rubber prices may lead to adjustments in resource allocation and long-run market conditions that subsequently affect coffee pricing.

Regarding international rubber prices, short-term changes up to the third lag (D(LnX4S), D(LnX4S(-1)), D(LnX4S(-2)), D(LnX4S(-3))) are statistically insignificant, suggesting a lack of immediate transmission from world rubber price movements to domestic Robusta coffee prices. Interestingly, the fourth lag (D(LnX4S(-4))) shows a strongly positive and statistically significant relationship, with a coefficient of 0.128051 and a p-value of 0.0000, significant at the 1% level. This indicates that increases in international rubber prices four days earlier are positively associated with current Indonesian Robusta coffee prices. This relationship may be due not to direct substitution effects but to shared market dynamics or international risk spillovers in commodity futures markets, particularly if both commodities are influenced by global macroeconomic or financial market trends.

The price of Indonesian Robusta coffee was impervious to fluctuations in cocoa and rubber prices in both domestic and international markets, since the markets for these commodities are unrelated in terms of market types, supply channels, market segments, industrial business cycle, and other specific factors affecting these markets (Delle Chiaie *et al.*, 2022). The cocoa market is largely distributed to manufacturing industries to produce intermediate and final food and beverage products. Whilst most natural rubber products are targeted to be marketed for industrial uses, such as automotive and other industries (Huang *et al.*, 2023). In this case, the market price was established differently, meaning that fluctuations in cocoa and rubber commodity prices were not entirely transmitted to the Robusta coffee price. Despite cultivating space as potential substitutes for each other, the decision to supplant Robusta coffee with other crops will not manifest immediately in the short term, particularly during the surge in cocoa and rubber prices.

Furthermore, the coefficient for the current period exchange rate (LnX5K) is -0.373576, which is statistically significant at the 1% level ($p < 0.01$). This reflects a negative and significant contemporaneous effect of the exchange rate on the Indonesian Robusta coffee prices. It means a 1% depreciation of the Indonesian Rupiah is associated with a 0.37% decrease in the domestic price of Robusta coffee in the same period, ceteris paribus. However, this finding deviates from the theoretical perspective, so it should be interpreted with several underlying conditions. Usually, a depreciation of the local currency is expected to make coffee as an export commodity more competitive in the global market (Aklimawati & Wahyudi, 2013; Wanzala *et al.*, 2024), thereby increasing the domestic price of export products due to rising foreign demand or reduced domestic supply.

The negative impact is observed only in the same period, while the coefficient of the lagged exchange rate (LnX5K(-1)) is 0.375852, which points out a positive and significant effect. This suggests a delayed price transmission mechanism, in which the favorable effects of depreciation on domestic coffee prices are not immediate but materialize in subsequent periods. In such a case, the effect of exchange rate changes on domestic Robusta prices becomes less direct or delayed, considering the uncertainty of the global economy. The nearly symmetric magnitude of the current and lagged coefficients (approximately ±0.375) implies that the net effect of a one-time exchange rate shock may neutralize over two periods, suggesting a short-run price suppression followed by a subsequent rebound.

Subsequently, a cointegration test and its validation checking were performed to ascertain the reliability and validity of the regression equation using the ARDL model. Several findings emerged regarding the relationship between the Indonesian Robusta coffee price and explanatory variables. The bounds test results in Table 3 revealed that the F-statistic significantly exceeded the critical value upper bounds I(1) at a 1% significance level. This established a robust long-run cointegration relationship between the Indonesian Robusta coffee price and substitute commodity prices (Arabica coffee, cocoa, and rubber) in domestic and international markets, besides the exchange rate. Consequently, Indonesian Robusta coffee price will co-movement with substitute commodity prices and the exchange rate over the long run, despite short-run fluctuations.

Table 3. Analysis results of the cointegration test and the error correction model approach in validating the robustness of the ARDL-ECM model

Cointegration test	Test statistic		Critical value bounds		
			Significance	I(0) Bound	I(1) Bound
ARDL bounds test	F-statistic	50.46998 ***	10 %	1.83	2.94
	k	10	5 %	2.06	3.24
	H_0	Rejected	2.5 %	2.28	3.50
			1 %	2.54	3.86
Model validation					
	Variable	Coefficient	Std. error	t-Statistic	Probability
Error correction regression	CointEq(-1)	-1.626317	0.073001	-22.277866	0.0000
Estimation of short-run relationship					
	Test statistic	Value	df	Probability	H_0
Wald test	F-statistic	126.9729	(19, 1229)	0.0000 ***	Rejected
	Chi-square	2412.485	19	0.0000 ***	Rejected

Notes: ***Significant at 1% level
**Significant at 5% level
* Significant at 10% level

While cointegration was present, estimating the error correction model was crucial to affirm the validity of the ARDL model. This demanded two essential criteria: the coefficient was expected to be negative, and the associated p-value should be below the 5% threshold to confirm statistical significance. The fulfillment of both conditions confirmed a long-run causal relationship, reflecting a strong adjustment mechanism that enables the correction of short-run disequilibria toward long-run equilibrium. The empirical results indicated that the CointEq(-1) coefficient was negative and statistically significant, with a p-value below the 5% significance level. Notably, the estimated CointEq(-1) value of -1.626317 suggested a rapid speed of adjustment—approximately 162%—indicating that deviations from the short-run equilibrium are corrected swiftly. This result revealed that Indonesian Robusta coffee prices exhibit high responsiveness to short-run imbalances.

Moreover, the Wald test showed an F-statistic of 126.9729 with a corresponding p-value of 0.0000, indicating that all explanatory variables in the model simultaneously exert a statistically significant influence on the dependent variable—Indonesian Robusta coffee price—at the 5% significance level. The null hypothesis was rejected, indicating the robustness of the ARDL model in capturing the short-run dynamics of Indonesian Robusta coffee price. These findings provided empirical evidence that fluctuations in the prices of substitute commodities, such as Arabica coffee, cocoa, and rubber, in both domestic and international markets, along with the exchange rate, significantly affected the price behavior of Indonesian Robusta coffee in both the short and long run.

Table 4 presents a comprehensive overview of the causal relationships between the independent variables and the Indonesian Robusta coffee price, reversely. The ARDL-ECM model revealed three causality linkages: bidirectional, unidirectional, and no causality. Notably, a statistically significant bidirectional causality was observed among the Indonesian Robusta coffee price and various international cocoa prices, such as the New York cocoa price, London cocoa price, and cocoa indicator price. The results of the Granger causality test decisively rejected the null hypothesis, with p-values of the F-statistics falling

Table 4. Results of the Granger causality test among the Indonesian Robusta coffee price and the independent variables

Variable		Hypothesis	p-value	H_0	Relationship	Direction
Dependent	Independent					
D(LnYI)	D(LnX1L)	D(LnX1L) does not Granger cause D(LnYI)	2.E-14 ***	Rejected	D(LnYI) ✇ D(LnX1L)	Unidirectional
	D(LnX2I)	D(LnX2I) does not Granger cause D(LnYI)	0.2013	Accepted	-	No causality
	D(LnX2N)	D(LnX2N) does not Granger cause D(LnYI)	0.3533	Accepted	-	No causality
	D(LnX3I)	D(LnX3I) does not Granger cause D(LnYI)	0.0545 *	Rejected	D(LnYI) ✇ D(LnX3I)	Unidirectional
	D(LnX3N)	D(LnX3N) does not Granger cause D(LnYI)	8.E-07 ***	Rejected	D(LnX3N)↔D(LnYI)	Bidirectional
	D(LnX3L)	D(LnX3L) does not Granger cause D(LnYI)	0.0002 ***	Rejected	D(LnX3L)↔D(LnYI)	Bidirectional
	D(LnX3C)	D(LnX3C) does not Granger cause D(LnYI)	3.E-06 ***	Rejected	D(LnX3C)↔D(LnYI)	Bidirectional
	D(LnX4I)	D(LnX4I) does not Granger cause D(LnYI)	0.8763	Accepted	-	No causality
	D(LnX4S)	D(LnX4S) does not Granger cause D(LnYI)	0.8805	Accepted	-	No causality
	D(LnX5K)	D(LnX5K) does not Granger cause D(LnYI)	0.2731	Accepted	-	No causality

Notes: ***Significant at 1% level
**Significant at 5% level
* Significant at 10% level

below the 5% significance level. It confirms that various international cocoa prices Granger cause changes in Indonesian Robusta coffee price and conversely. These findings underscore the exchangeability of Robusta and cocoa have a mutually influential dynamic, potentially due to both commodities being internationally traded soft commodities with overlapping demand and market players. The interdependence of those commodities reflects underlying global commodity market linkages, including speculation, hedging strategies, shared supply chain channels, and others that respond to macroeconomic or climate-related shocks. A similar term, the co-movement between cross-commodity prices, is captured and influenced by microeconomic characteristics of supply and demand of the commodities and macroeconomic determinants, which are reinforcing their critical role in the construction of contemporary commodity pricing models and jointly modeling commodity markets (Schischke *et al.*, 2024).

Second, a unidirectional causality was identified between the Indonesian Robusta coffee price and the world Robusta coffee price, including the Indonesian cocoa price. One of the null hypotheses was decisively rejected as reflected by a statistically significant p-value of the F-statistic at the 1% and 10% significance level. These results revealed that the Indonesian Robusta coffee price Granger-causes the world Robusta coffee price and Indonesian cocoa price. This causality reflects that Indonesia has a substantial role in the global Robusta coffee market, as one of the world's main producers and exporters. Thus, fluctuations in Indonesian prices could signal future changes in the uncertainty of the international coffee market due to supplyside shocks, harvest conditions, and domestic trade regulations (Zhang *et al.*, 2022). Unidirectional relationships also flow in the price movement of domestic cocoa. It suggests that the price movement of Indonesian Robusta coffee helps predict changes in domestic cocoa price and not vice versa. Coffee and cocoa are different commodities; however, they have underlying economic or agricultural linkages as export products, which allow price signals in one market to influence another. Given that both have similar characteristics relating to market-sensitive commodities, fluctuations in coffee prices might be an early indicator of adjustments in Indonesian cocoa price behavior. It supports the statement that price escalations in one commodity market tend to trigger similar increases in related markets (Stavrakoudis & Panagiotou, 2017; Zhang *et al.*, 2019; Byrne *et al.*, 2020). Generally, these dynamic interactions between coffee and cocoa reflect the interdependency among the closest commodity substitutes.

Lastly, the results indicated no causality among several variables as identified by accepting the null hypothesis due to p-values of the F-statistic substantially exceeding the 10% significance level in both directions. Specifically, the findings confirmed that the price dynamics of Arabica coffee (domestic and international), rubber price (domestic and international), and the Rupiah exchange rate did not Granger-cause the Indonesian Robusta coffee price, and vice versa. Despite both being types of coffee grown in Indonesia, the market mechanisms driving Arabica and Robusta may differ due to any differences in market segmentation, consumer preferences, quality perception, and export destinations, which leads to the price fluctuations in the Arabica market being less responsive to Robusta prices. This disconnect is also found in the global Arabica market, considering Indonesia has a smaller role in the Arabica traded globally.

Similarly, no short-run causality between rubber prices and Robusta prices was found. Whilst both commodities could be cultivated in overlapping regions and potentially compete for agricultural land and farming systems, the price movements do not appear to influence each other. It concluded that rubber and Robusta coffee have different characteristics and distinct market dynamics concerning demand, supply, and other fundamental determinants. Hence, fluctuations in rubber prices have a negligible influence on Robusta coffee price movements. Additionally, exchange rates are commonly considered to affect export commodity prices traded in the global market. However, this result revealed that fluctuations in the Rupiah exchange rate do not Granger-cause Indonesian Robusta price due to some domestic pricing and policy mechanisms that buffer against currency volatility. As a macroeconomic variable, exchange rate movements indirectly or immediately impact the Indonesian Robusta coffee prices, and as such, the effects tend to manifest over a longer period. Therefore, it can be inferred that the exchange rate is not a significant driver of short-run price fluctuations in the Robusta coffee market.

The Autoregressive Distributed Lag (ARDL) model is widely recognized as a robust and reliable econometric approach, particularly when the regression classical assumptions are fulfilled. This modeling framework is especially well-suited for capturing short-run and long-run equilibrium relationships among variables, offering valuable insights into complex data interdependencies. In the present study, we selected a specific ARDL model order, denoted as (4, 4, 0, 1, 0, 0, 0, 0, 4, 4, 1), which was subjected to a series of diagnostic evaluations to verify compliance with key classical assumptions. The results of these diagnostic tests were presented in Table 5.

The results of the autocorrelation diagnostic indicated that the null hypothesis of no serial correlation cannot be rejected. This conclusion was shown by the p-value

Obs*R-squared of 0.9356 exceeding the significance level at $\alpha = 5\%$. The value of the Durbin-Watson (DW) statistic was 2.001897, which approximates or exceeds the critical value of 2 and falls within the acceptable range, defined as DU < DW < 4 – DU. This finding confirmed that the model has no serial correlation, thereby enhancing the credibility and reliability of the model's estimations.

Additionally, heteroscedasticity was analyzed using two statistical tests, as Breusch-Pagan-Godfrey Test and the White Test. The analysis revealed that the variance of the residuals varied across observations, as identified by a p-value of the F-statistic and Chi-squared of 0.0000. This exceptionally low p-value leads to rejection of the null hypothesis of homoscedasticity, indicating that the model's residuals are not homogeneously distributed. The presence of heteroscedasticity in the ARDL model observed in this study follows the findings reported by Ghouse *et al.* (2018), which the empirical analysis also identified a similar heteroscedastic pattern in the ARDL model. In the context of linear regression analysis, it is not uncommon for the error term to exhibit heteroscedasticity while the explanatory variables are simultaneously affected by multicollinearity, which are both econometric issues that inflate the variance of the parameter estimates, leading to biased or misleading statistical inference regarding the regression coefficients (Alabi *et al.*, 2020; Dar & Chand, 2025). In the absence of measurement error, it is well established that heteroscedasticity in the error term of linear models does not compromise the unbiasedness of ordinary least squares (OLS) coefficient estimates. However, assuming homoscedasticity under such conditions results in incorrect standard error estimates, which in turn lead to flawed statistical inference regarding the coefficients and unreliable prediction intervals (Romeo *et al.*, 2024).

Addressing the result of heteroscedasticity, a remedial measure was employed to mitigate the effects of that in regression analysis, which was White heteroscedasticity-

Table 5. Results of diagnostic checking of the ARDL model for Indonesian Robusta coffee price co-movement

Diagnostic checking	Method	Analysis results		Null hypothesis (H_0)
		Statistic	Value	
Autocorrelation	Breusch-Godfrey Test	F-statistic Probability Obs*R-squared Probability	0. 064953 0. 9371 0.133173 0. 9356	Accepted
	Durbin-Watson Test	Durbin-Watson Statistic DU = 1.92023; 4-DU = 2.07977 (n:1200; k:10) DU = 1.92153; 4-DU = 2.07847 (n:1250; k:10)	2.001897	Accepted
Heteroskedasticity	Breusch-Pagan-Godfrey Test	F-statistic Probability Obs*R-squared Probability	8.104970 0. 0000 196.0861 0. 0000	Rejected
	White Test	F-statistic Probability Obs*R-squared Probability	13.15972 0. 0000 1097.590 0. 0000	Rejected
Normality	Jarque-Bera Test	Jarque-Bera Probability	11332.45 0.0000	Rejected

consistent standard errors and covariance approach to validating robustness of the estimated models and supporting valid statistical inference regarding the parameters of the regression equation (Mak, 2000; Abbas, 2022; Dar & Chand, 2025). Implementing heteroscedasticity-robust standard errors did not change coefficient values and the probability of any independent variables, indicating that it consistently has no meaningful impact on the dependent variable, both before and after correction. However, a change occurred in the specific variables that the 4th lag of rubber prices (domestic and international). These two previously significant variables became statistically insignificant after applying White's robust standard errors. It suggests that the initial inference regarding the impact of lagged rubber prices was likely overestimated due to biased standard errors caused by heteroscedasticity. In this case, rubber prices fail to affect the Indonesian Robusta coffee price, reflecting the agricultural commodity markets' specialized and segmented nature. The correction ensures that statistical inferences are now more reliable and underscores the necessity of robust estimation in the presence of heteroscedasticity.

The evaluation of residual normality revealed a more nuanced outcome. The Jarque-Bera test, applied to assess the normality of the residual distribution, returns a p-value of 0.0000, which was below the 5% significance level. Consequently, the null hypothesis that normally distributed residuals was rejected, indicating a departure from normality. While this result might initially raise concerns, particularly given the traditional emphasis on normality in classical regression assumptions, an alternative interpretation grounded in the Central Limit Theorem (CLT) offers a mitigating perspective. According to the CLT, the sampling distribution of the sample mean tends to approximate normality as sample size increases (Hays, 1994; Islam, 2018; Smith & Taylor, 2017). Empirical literature suggested that sample sizes exceeding 30 generally provide sufficient grounds for invoking the CLT, diminishing the importance of strict normality in residuals. Although Smith & Taylor (2017) caution against overgeneralization, arguing that samples between 20 and 100 warrant scrutiny, their findings also acknowledged that sample sizes above 100 substantially alleviate concerns related to non-normality. Accordingly, in case of a sufficiently large sample, the deviation from residual normality observed here is unlikely to compromise the validity of inference drawn from the model.

In support of this interpretation, Islam (2018) used a substantial sample of 1,000 observations to reinforce the applicability of the Central Limit Theorem (CLT), while Maïnassara & Rabehasaina (2025) further validated the theorem using large-scale datasets, thereby confirming the robustness of normality assumptions under extensive sampling conditions. These findings were consistent with the present study, which utilizes a dataset comprising over 1,000 observations. Given the sample size, it is reasonable to infer that the residuals of the ARDL model for Indonesian Robusta coffee price approximate a normal distribution. It is also important to recognize that violations of the normality assumption are not uncommon in social science research, where many empirical variables inherently exhibit non-normal distributions (Micceri, 1989; Islam, 2018). Thus, in the context of large samples, such deviations are unlikely to undermine the reliability of the model's inferences.

CONCLUSION

The comprehensive analysis conducted in this study pointed out several significant insights into the pricing behavior of Indonesian Robusta coffee:

1. The results derived from the Autoregressive Distributed Lag–Error Correction Model (ARDL–ECM) indicated the presence of statistically significant long-run and short-run equilibrium relationships at the 1%, 5%, and 10% significance level. Specifically, the Indonesian Robusta coffee price was cointegrated with (1) its past values, (2) the world Robusta coffee price and its past value, (3) the Indonesian Arabica coffee price, (4) the 1^{st} lag of world Arabica coffee price, (5) London cocoa price, and (6) the Rupiah exchange rate and its past value. Conversely, the prices of unrelated substitute commodities—namely rubber—and the Indonesian, New York, and cocoa indicator prices, were not significantly long-run integrated with Indonesian Robusta coffee prices.
2. The Granger causality test explained the bidirectional causality between the Indonesian Robusta coffee price and New York, London's cocoa, and the indicator's cocoa prices. Additionally, unidirectional causality was detected from the Indonesian Robusta coffee price toward the prices of Indonesian cocoa and world Robusta commodities. Notably, this study found no causal relationships involving Arabica prices, rubber prices, and the exchange rate, highlighting the selective nature of market interdependencies and delayed response on the price transmission mechanism.
3. The findings suggested that price co-movements were predominantly confined to closely related commodities. In contrast, unrelated commodities, such as rubber, showed distinct pricing behaviors that did not align with the Indonesian Robusta coffee price, further emphasizing structural differences across agricultural markets.
4. An upsurge in the world Robusta coffee price, Indonesian Arabica coffee price, and London cocoa price signaled a broader expansion in the primary agricultural commodity sector. This upward trend contributed to elevating Indonesian Robusta coffee prices, reflecting the sector's sensitivity to international market changes and reinforcing the interconnectedness of world agricultural commodity pricing.

These findings deepened our understanding of the structural and causal underpinnings of the Indonesian Robusta coffee market. It also underscored the importance of related commodity markets and global economic signals in shaping domestic price movements—insights that are particularly valuable for smallholders, market players, policymakers, investors, and stakeholders within the agricultural sector.

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