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Domestic Crude Palm Oil Price and Its Production in Malaysia: Does It Has Asymmetric and Linear Relationship?

(Harga Minyak Sawit Mentah dan Pengeluarannya di Malaysia : Adakah Ia Mempunyai Hubungan Assimetri dan Linear?)

Mohd Abdul Hamid Hashim
UNITAR International University

Nik Hasfizul Hassan
UNITAR International University

ABSTRACT

This research investigates the long-run relationship between domestic crude palm oil (CPO) prices and production in Malaysia, focusing on the existence of co-integration, linearity, and symmetry in their interactions. Using monthly data from 2015 to 2019, the analysis applies several econometric techniques, including the Granger causality test, Johansen co-integration approach, Autoregressive Distributed Lag (ARDL) model, and Nonlinear ARDL (NARDL) framework. The empirical findings from the Granger causality, Johansen co-integration, and ARDL analyses confirm a long run co-integrating relationship between domestic CPO prices and production. The ARDL results establish a significant linear association, while the NARDL model provides further evidence of a symmetric long-run relationship between the two variables. Additionally, the findings show that domestic CPO prices are endogenous within the system, whereas inflation emerges as the most exogenous factor. Crucially, domestic CPO production exerts a direct and statistically significant influence on price determination. The impulse response function (IRF) analysis indicates that shocks to the system dissipate within six months, with complete normalization occurring approximately three months later, as reflected in the persistence profile (PP). Overall, the study contributes to the literature by demonstrating that production quantity serves as the primary determinant of domestic CPO prices, thereby challenging the classical supply theory that traditionally views price as the main driver of production levels.

Keywords : Crude palm oil; domestic; export; production; variable

ABSTRAK

Kajian ini meneliti hubungan antara harga minyak sawit mentah (MSM) domestik dan tahap pengeluarannya dalam jangka panjang di Malaysia, dengan memberi tumpuan kepada kewujudan hubungan ko-integrasi, sifat lineariti, serta tahap simetri dalam interaksi antara kedua-dua pembolehubah tersebut. Menggunakan data bulanan bagi tempoh 2015 hingga 2019, kajian ini mengaplikasikan kaedah ekonometrik seperti ujian kausaliti Granger, ujian ko-integrasi Johansen, model Autoregresif Lengah Teragih (ARDL) serta model ARDL bukan linear (NARDL). Dapatan daripada ujian Granger, Johansen dan ARDL mengesahkan kewujudan hubungan ko-integrasi jangka panjang antara harga dan pengeluaran MSM domestik. Model ARDL menunjukkan hubungan linear yang signifikan, manakala model NARDL mengesahkan hubungan simetri dalam jangka panjang. Keputusan turut menunjukkan bahawa harga MSM bersifat endogen, manakala inflasi merupakan faktor paling eksogen dalam sistem. Selain itu, pengeluaran MSM domestik didapati mempunyai pengaruh langsung dan signifikan terhadap penentuan harga. Analisis fungsi tindak balas impuls menunjukkan sebarang kejutan dalam sistem kembali stabil dalam tempoh enam bulan. Secara keseluruhan, kajian ini menegaskan bahawa kuantiti pengeluaran berperanan penting dalam menentukan harga MSM domestik, sekali gus mencabar teori klasik penawaran yang menganggap harga sebagai penentu utama kepada kuantiti dibekalkan.

Kata kunci : Minyak sawit mentah; tempatan; eksport; pengeluaran; pembolehubah

JEL : C100, C530, D240, M210, 047, Q110

INTRODUCTION

This study explores both the symmetric and asymmetric relationships, as well as the linear and nonlinear dynamics, between domestic crude palm oil (CPO) prices and production in Malaysia. It also investigates the existence of long-run co-integration between these variables while incorporating key macroeconomic determinants. Interest rates, through their effect on the Consumer Price Index (CPI), are widely acknowledged to significantly influence the real prices of goods and services, including both domestic and export CPO prices. Recognizing the complex nature of price formation in the palm oil industry, this research seeks to identify the primary factors directly influencing domestic CPO prices and to evaluate their degree of exogeneity. Empirical evidence from prior studies reinforces this analytical framework. For instance, Hidayat et al. (2024) reported that domestic production, price, and export volume exert substantial effects on domestic CPO prices. Likewise, Prawoto and Gusnia (2024) highlighted the impact of inflation, while Bahar et al. (2023) emphasized the significance of the CPI. Collectively, these findings provide a robust empirical basis for the selection of variables in the current research.

In summary, this research seeks to address the following key research questions: RQ1: Do domestic CPO price and production exhibit a symmetric or asymmetric relationship in the short run and/or long run? RQ2: Is the relationship between these variables linear or nonlinear, both in the short run and long run? RQ3: Which variable acts as the leader and which as the follower within the dynamic relationship? RQ4: To what extent do CPO export components, domestic CPO production, inflation, and the consumer price index (CPI) significantly influence domestic CPO prices? RQ5: Among the variables examined, which are the most exogenous and which are the least exogenous? RQ6: In the event of a disturbance to an exogenous variable, how long does it take for the system to return to equilibrium? RQ7: How does the system respond to a system-wide shock affecting the relationships among variables, and what is the duration required for the system to restore equilibrium?

This research addresses its research questions using time series techniques, specifically the Nonlinear Autoregressive Distributed Lag (NARDL) model to examine asymmetric relationships (Dangal et al. 2023) and the Autoregressive Distributed Lag (ARDL) model to analyse linear relationships (Ashiagbor et al. 2023; Hoang et al. 2016). Time series methods are widely recognized for their accuracy and reliability in forecasting (Effrosynidis 2023). The choice of ARDL and NARDL models is justified by their capacity to effectively capture asymmetric effects and to explore co-integration relationships (Munene 2023; Simran & Sharma 2023).

Furthermore, this research enhances the understanding of the long-run co-integration between domestic CPO prices and production in Malaysia, uncovering a linear and symmetric long-term relationship that aligns with the traditional upward-sloping supply curve (Sisodiya et al. 2023; Ghazanfar 2013). The results reveal that domestic CPO prices are endogenous, inflation is the most exogenous variable, and domestic CPO production exerts a direct and significant influence on domestic prices. Additionally, the impulse response analysis indicates that when the system experiences a shock, equilibrium is restored within approximately six months. A key contribution of this research lies in its novel perspective on palm oil supply dynamics, emphasizing that production quantity decisively determines price—a finding that challenges the classical supply theory, which traditionally holds that price drives the quantity supplied.

The following of this paper is organized as follows: Section 2 reviews the pertinent literature; Section 3 describes the research methodology, detailing the Granger causality test, Johansen co-integration, ARDL, and NARDL models, and explains the rationale for their use; Sections 4 and 5 present the empirical findings and conclusions, respectively.

LITERATURE REVIEW

The existing body of research on crude palm oil (CPO) has examined a wide range of issues related to price behavior, production trends, and macroeconomic influences. This review synthesizes previous studies from Malaysia and other countries, highlighting gaps in the literature and establishing the rationale for the present investigation.

Several previous studies, including those by Khusairi (2018) and Noor et al. (2024), have concentrated on forecasting trends in Malaysia's CPO sector. Khusairi (2018) observed that CPO production recovered by 2017 following the El Niño disruptions of 2015–2016 and was expected to continue growing into 2018, despite a projected decline in prices. Likewise, Noor et al. (2024) forecasted a moderate increase in yield, from 16.73 tonnes per hectare in 2020 to 16.89 tonnes per hectare by 2030. Although these studies offer important insights into production projections, they do not empirically investigate the long-run relationship between domestic CPO price and production.

In contrast, Tan et al. (2023) investigated the presence of asymmetric relationships between palm oil prices and climate variables using the ARDL approach, covering data from 1964 to 2016. Their findings revealed a strong long-run asymmetry, particularly between prices and temperature, where decreases in temperature had a more pronounced impact than increases. However, rainfall exhibited a symmetric but negligible long-run effect. Although this study contributes to the literature on asymmetry, it focuses on climate variables rather than production–price interactions.

From a regional perspective, Songsiengchai et al. (2018) analyzed the transmission of global commodity prices to domestic CPO prices in Thailand using a Vector Error Correction Model (VECM). Their results showed that Malaysian CPO prices positively influenced Thai CPO prices and that there was bidirectional causality between Malaysian CPO and global soybean oil prices. While the study highlights the regional interconnectedness of CPO markets, it does not explore domestic supply-side dynamics in Malaysia.

Webb (2018) treated commodity prices as leading indicators of inflation, employing Granger causality tests to demonstrate that aggregate commodity prices can forecast overall price movements. This finding offers theoretical justification for examining the relationship between CPO prices, inflation, and the consumer price index (CPI). Nevertheless, the study's analysis remained at an aggregate level and did not explore the specific dynamics of the palm oil sector.

Bentivoglio et al. (2018) examined the determinants of palm oil production in Indonesia, focusing on its use for food and biofuel. Their results highlighted the importance of government policies and plantation expansion, with all analysed factors showing significant positive impacts on production. However, while insightful, the study did not explore the interrelationship between production and price.

Sabar and Kamil (2023) applied stochastic frontier analysis (SFA) to assess the technical efficiency of CPO production across Malaysian states. They identified labor, time, and mill capacity as significant inputs and observed increasing technical efficiency over time. Notably, the inefficiencies were attributed to technical rather than scale inefficiencies. While this provides insights into production dynamics, it does not engage with price behavior.

Hassan et al. (2023) examined long-term causal relationships between Malaysian palm oil exports with macroeconomic factors such as GDP growth, consumption, vegetable oil production, and exchange rates, using panel data from ten major importing countries. The findings indicated that palm oil exports were negatively affected by economic growth and alternative oil production. Though relevant for understanding demand-side forces, the study overlooks the domestic price–production relationship.

Lastly, Supriya and Mamilla (2024) explored the relationship between CPO market variables and global crude oil prices using the ARDL model. Using data spanning the period from 2011 to 2022, their study identified a significant long-run linkage between CPO prices and movements in global oil markets. While this finding underscores the impact of external price factors on CPO, it does not consider the influence of domestic production on CPO price dynamics.

In summary, the existing body of literature provides comprehensive understanding of the dynamics of the CPO market, covering areas such as price forecasting, production efficiency, and international market interactions. A variety of studies have utilized robust econometric techniques, such as the ARDL model, VECM, and Granger causality tests, to explore the effects of external factors on CPO prices and production. However, a notable research gap remains regarding the long-run relationship between domestic CPO prices and domestic production in Malaysia. Limited research has examined whether this relationship exhibits co-integration, linearity, and symmetry over time.

Addressing this gap forms the core objective of this research, which aims to advance the current understanding of Malaysia's CPO market by presenting new empirical evidence on its structural dynamics. This is accomplished through the application of advanced econometric methods, such as co-integration testing, the ARDL framework, and the NARDL approach.

METHODOLOGY

This section is an important part of the study because it elaborates on detailed steps for the time series techniques that will be run based on the collected data.

SOURCE OF DATA

Monthly data on crude palm oil (CPO) clarity from the Malaysian Palm Oil Board (MPOB) official website, which provides reliable and comprehensive industry-specific information. The study employs a total of sixty monthly observations encompassing the period from January 2015 to December 2019. In time series analysis, a minimum of thirty observations considered sufficient for robust statistical inference (Su et al. 2023). Monthly data clarity chosen for this analysis as they offer an optimal balance between granularity and stability, being less volatile than daily data while capturing more temporal dynamics than quarterly data (Kucher et al. 2024; Badeeb & Lean 2017).

SELECTED ANALYSIS TOOLS

This research utilizes a time series methodology using the Microfit 5.5 software package. Additionally, Stata version 1.1 used to estimate the NARDL model, which is particularly effective in capturing asymmetric relationships. The raw data, spanning the period from January 2015 to December 2019, presented in Table 1. As shown in Table 2, the variables transformed into their logarithmic and differenced forms. The logarithmic transformation applied primarily to stabilize variance and reduce heteroscedasticity, while also enabling the interpretation of relationships in terms of elasticities. Differencing performed to achieve stationarity in the mean, a necessary condition for many time series analyses, whereas the NARDL framework allows for the preservation of long-run theoretical relationships even when variables integrated of different orders.

TABLE 1. Malaysia CPO's average price, domestic production, export tonnage and export turnover: The year 2014-2018

Year	Average Domestic Price (RM/Tonne)	Domestic Production (000 Tonne)	Export Volume(000 Tonne)	Export Turnover(000,RM)
2015	2,393.58	19,667.02	4,700.62	11,469,780.00
2016	2,195.46	19,964.04	5,275.04	11,569,860.00
2017	2,558.88	17,319.18	3,822.59	9,709,240.00
2018	2,897.17	19,919.35	2,519.47	7,223,280.00
2019	2,237.38	19,516.14	3,394.52	7,822,180.00
2020	2,393.58	19,667.02	4,700.62	11,469,780.00

Source: Economic and Industry Development Division, MPOB

TABLE 2. Variable selected in analyze on malaysia palm oil

No.	Indicator/Variable	Unit	Label
1.	Domestic CPO's Average Price	RM/Metric Tonne	PR
2.	CPO's Domestic Production	Thousands Metric Tonne	PROD
3.	CPO's Export	Thousand Metric Tonne	TXPORT
4.	CPO's Export Volume	Thousand RM	RMXPORT
5.	CPO's Export Price	RM/Metric Tonne	PXPORT
6.	Inflation Rate	Percentage	INF
7.	Consumer Price Index	Current	CPI

UNIT ROOT TEST

To evaluate the stationarity characteristics of the transformed data, two widely used unit root tests, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, applied. These tests performed to determine whether the variables are non-stationary at their level (in logarithmic form) and become stationary after first differencing. Establishing the correct order of integration is an essential preliminary step before conducting further time series analyses, such as co-integration testing, vector autoregressive (VAR) lag selection, and the estimation of ARDL or NARDL models. Once the unit root tests confirm the integration order of the variables, the results can reliably use in subsequent empirical analyses.

DETERMINANT OF VECTOR AUTOREGRESSIVE (VAR) ORDER

In this step, the optimal lag length for each variable is determined using standard lag selection criteria, specifically the Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (SBC). These criteria are used to determine the optimal lag length, striking a balance between model fit and complexity. Typically, the lag length corresponding to the lowest AIC or SBC value is selected, as it represents the best trade-off between goodness of fit and model parsimony. While formal hypothesis testing based on p-values is not directly applied in AIC or SBC selection, likelihood ratio tests may be used in certain contexts—such as in Vector Autoregression (VAR) models, to validate the adequacy of the chosen lag order.

The identified lag structure is critical for the robustness of subsequent time series analyses, including unit root testing, co-integration analysis, and model estimation (e.g., ARDL or NARDL). Appropriate lag selection ensures that residuals exhibit desirable statistical properties and that the model effectively captures the underlying temporal dynamics without overfitting.

DETERMINANT OF CO-INTEGRATION

This research seeks to determine whether the chosen variables demonstrate a long-term relationship using co-integration analysis. To this end, several econometric approaches were employed, including the Engle–Granger two-step method, the Johansen co-integration technique, and the ARDL and NARDL models. The ARDL methodology offers a key advantage in that it can accommodate a combination of stationary $[I(0)]$and non-stationary $[I(1)]$variables without requiring all series to be integrate into the same order.

In the ARDL bounds testing framework, the presence of co-integration is assessed using the F-statistic (Wald test). If the calculated F-statistic exceeds the upper critical bound, it indicates the presence of a long-run co-integrating relationship among the variables. The ARDL methodology proceeds in two key stages. In the first stage, the test determines whether a long-run relationship exists by comparing the calculated F-statistic with the critical bounds or by evaluating the p-value. A p-value below 0.05 (at the 5% significance level) or 0.10 (at the 10% significance level) leads to the rejection of the null hypothesis of no co-integration. Once co-integration is established, the second stage estimates the long-run coefficients to identify the magnitude and direction of relationships among the variables. These coefficient estimates offer valuable insights into the long-term dynamics of the system and form a basis for informed policy formulation and forecasting.

DETERMINANT LONG RUN STRUCTURAL MODEL (LRSM)

After determining the optimal lag order in the co-integration test, the LRSM approach is applied to assess whether the variables share a long-term equilibrium relationship. This procedure involves two types of hypotheses testing within the co-integration framework: exact identification and over-identification.

The exact identification test is performed by normalizing the coefficients, achieved by imposing a restriction on the key variable that acts as the dependent variable in this research. This normalization allows for a clearer and more meaningful interpretation of the long-run equilibrium relationship. Subsequently, the over-identification test evaluates the validity of additional restrictions imposed on the co-integrating vectors to ensure their consistency with the empirical data.

The validity of these restrictions is assessed using the chi-square (χ^2) statistic. A p-value below 0.05 leads to the rejection of the null hypothesis, indicating that the imposed restrictions are not supported by the data. Conversely, a p-value above 0.05 means the null hypothesis cannot be rejected, implying that the restrictions are valid and theoretically acceptable. In the LRSM framework, retaining the null hypothesis supports the soundness of the specified model structure.

Furthermore, the statistical significance of individual coefficients is evaluated using the t-ratio, where a value exceeding an absolute threshold of 2 denotes significance at the 5% level. This process ensures that the long-run parameter estimates are statistically robust, economically meaningful, and consistent with established theoretical expectations.

DETERMINANT OF VECTOR ERROR CORRECTION MODEL (VECM)

VECM is employed to differentiate endogenous from exogenous variables. This step is crucial for identifying which variables act as leaders (strongly exogenous) and which function as followers (weakly exogenous) within the system. Exogeneity is assessed by testing the null hypothesis that a variable is exogenous; a variable is deemed exogenous if its associated p-value exceeds 0.05, indicating that its fluctuations are not significantly influenced by other variables in the system.

Additionally, the VECM framework allows for the analysis of both short-run and long-run Granger causality, offering insights into the direction and dynamics of causal relationships over time (Masih et al. 2010; Abdallah 2024). This information is particularly valuable for policy making, as it identifies which variables predominantly drive system dynamics and which variables respond to changes in others or to external shocks.

DETERMINANT OF VARIANCE DECOMPOSITION (VDC)

VDC is applied to evaluate the relative exogeneity of variables by measuring their contributions to the forecast error variance across specified time horizons. This method calculates and presents the percentage of each variable's forecast error variance that can be attributed to shocks from all variables in the system at selected intervals. By doing so, VDC reveals the extent to which the historical movements of each variable explain fluctuations in the system, enabling the identification of the leading (most exogenous) variables.

In this research, 12-month and 24-month horizons, representing one- and two-year periods, are used for analysis. Based on the VDC results, variables are ranked from 1 to 7, where 1 denotes the highest exogeneity and 7 indicates the highest endogeneity. This ranking provides a clear hierarchy, reflecting the relative influence and responsiveness of each variable within the dynamic system.

DETERMINANT OF IMPULSE RESPONSE (IP)

IP analysis is employed to examine how a shock to one variable influence other variable within the system, capturing both the magnitude and duration of their responses. This method traces the time-path of dependent variables following a one-time innovation in each system variable. Variables that are weaker or more dependent (endogenous) typically show stronger and more persistent reactions to shocks from leading (exogenous) variables, offering important insights into the system's dynamic adjustment processes.

DETERMINANT OF PERSISTENCE PROFILE

Persistence Profile Analysis (PPA) conducted to assess the duration and stability of the system's response when all variables simultaneously exposed to external shocks. This approach evaluates the time needed for the system to revert to its long-run equilibrium and examines the extent of stabilization following such disturbances. A quicker return to equilibrium reflects a more stable and resilient system, whereas a longer adjustment period indicates greater sensitivity to shocks and slower convergence.

RESULTS AND DISCUSSION

This section presents a discussion of the long-term time series statistical tests conducted on the variables included in the model.

UNIT ROOT TEST

The results of the unit root tests are critical for determining the suitability of subsequent co-integration analyses. For co-integration testing to be valid, the data series should be non-stationary in their level form (log-transformed), typically integrated of order one, I(1), and become stationary after first differencing, i.e., integrated of order zero, I(0). In this study, raw data were first converted to logarithmic form, and level variables were different to achieve stationarity. If variables remain non-stationary at levels, conventional statistical inference becomes unreliable, potentially leading to spurious regression results due to non-constant variances and trending behavior over time. However, differencing to achieve stationarity eliminates long-term trend information, restricting the analysis to short-run relationships and limiting the ability to examine theoretical long-term linkages (Masih et al. 2010).

Both the ADF and PP unit root tests were conducted on the log-transformed and differenced variables. As shown in Table 3(a), the ADF test results provide sufficient evidence to proceed with co-integration testing. Optimal lag lengths were selected based on the Schwarz Bayesian Criterion (SBC) and the Akaike Information Criterion (AIC), with consistent results supporting the chosen lag structure. Because the ADF test may not fully account for heteroskedasticity, the PP test was also employed, as it corrects for both autocorrelation and heteroskedasticity in the error terms.

Table 3(b) reveals some inconsistencies in the PP test results between the level and differenced forms. Only three variables, the logarithm of the export price of CPO, inflation, and the CPI, were found to be stationary. The export price of CPO remained non-stationary, aligning with the findings of Okon (2023). Despite these discrepancies, the robust and consistent findings from the ADF test provide sufficient justification to proceed to subsequent stages of the analysis.

TABLE 3(a). Augmented Dicker Fuller findings results (Computations include intercept with linear trend)

No.	Variable	Test Statistic	Critical Value	Implications
		Findings At Level/Log Form		
1.	LPR	-2.5597	-3.4689	Non-Stationary
2.	LPROD	-2.8843	-3.4689	Non-Stationary
3.	LTXPORT	-3.2351	-3.2351	Non-Stationary
4.	LRMXPORT	-3.2231	-3.2231	Non-Stationary
5.	LPXPORT	-1.7067	-3.4124	Non-Stationary
6.	INF	-1.1136	-3.3636	Non-Stationary
7.	CPI	-2.3756	-3.4503	Non-Stationary
		Findings At Difference Form		
1.	DDPR	-10.4589	-3.5405	Stationary
2.	DDPROD	-12.1441	-3.5405	Stationary
3.	DDTXPORT	-3.8785	-3.5833	Stationary
4.	DDRMXPORT	-4.5109	-3.5833	Stationary
5.	DDPXPORT	-4.6454	-3.5405	Stationary
6.	DINF	-2.9889	-3.5598	Stationary
7.	DCPI	-6.3663	-3.5405	Stationary

TABLE 3(b). Phillips-Perron test results (computations include intercept and linear trend)

No.	Variable	Test Statistic	Critical Value	Implications
		Findings At Level/Log Form		
1.	LPR	-4.6915	-3.4621	Stationary
2.	LPROD	-8.1768	-3.4621	Stationary
3.	LTXPORT	-4.9307	-3.4621	Stationary
4.	LRMXPORT	-5.1496	-3.4621	Stationary
5.	LPXPORT	-1.3542	-3.4621	Non-Stationary
6.	INF	-2.2710	-3.4064	Non-Stationary
7.	CPI	-1.9422	-3.4621	Non-Stationary
		Findings At Difference Form		
1.	DDPR	-17.1877	-3.5052	Stationary
2.	DDPROD	-33.2082	-3.5052	Stationary
3.	DDTXPORT	-18.8213	-3.5052	Stationary
4.	DDRMXPORT	-19.3267	-3.5052	Stationary
5.	DDPXPORT	-2.9531	-3.5052	Non-Stationary
6.	DINF	-9.3419	-3.5486	Stationary
7.	DCPI	-6.9199	-3.5052	Stationary

DETERMINE VECTOR AUTOREGRESSIVE (VAR) ORDER

The optimal lag length was determined by evaluating the AIC and the SBC, with the lag length corresponding to the lowest criterion values selected. As shown in Table 4, the model's maximum lag order identified as two. The VAR analysis further confirms that the data achieve mean stationarity after two lags (Suharsono et al. 2023). Consequently, lag orders of one or two considered suitable for the subsequent co-integration and causality analyses.

TABLE 4. Finding of determination of vector autoregressive (VAR) orders

Order	AIC	SBC	p-value on LR Test	p-value Adjusted LRTest
2	43.9005	-133.6627	0.000	0.001
1	15.6056	-114.1521	0.000	0.025

THE CO-INTEGRATION TEST

The results of the Engle–Granger co-integration test are presented in Table 5(a), showing the lowest SBC and the highest AIC values. However, due to the lack of appropriate critical values, definitive conclusions regarding the statistical significance of co-integration could not be drawn at this stage. To address this, a trial-and-error approach was undertaken by excluding one variable (LCPI), reducing the model from seven to six variables. As shown in Table 5(b), the revised model exhibits the highest AIC (64.5110) and lowest SBC (63.5354) values. Notably, the t-statistic (−5.7303) exceeds the critical value (−5.0382) in absolute terms, providing sufficient evidence to reject the null hypothesis of no co-integration and confirming the presence of a long-run equilibrium relationship among the variables. Variables such as the inflation rate, CPI, domestic CPO price, and export components appear co-integrated, likely due to their shared price-related characteristics. Nevertheless, the precise number of co-integration vectors remains undetermined, warranting further analysis using the Johansen co-integration test.

The Johansen test results, presented in Table 5(c), indicate the presence of a single co-integrating vector among the variables. This conclusion is supported by both the maximum eigenvalue and trace statistics, which exceed their respective critical values at the 95% and 90% confidence levels for r = 1. Based on these findings and theoretical considerations, it is concluded that one stable long-run co-integrating relationship exists in the model. The test is conducted on variables in their level (logarithmic) form, preserving long-term equilibrium information via the stationarity of the error correction term. The co-integrating vector includes variables such as CPO production volume, export volume, export sales, export price (Hidayat et al. 2024), and the domestic interest rate (Prawoto & Gusnia 2024), aligning with economic theory and the structural dynamics of Malaysia's domestic crude palm oil market.

Table 6 displays the ARDL co-integration test results, providing further evidence of a long-run linear relationship among the variables. F-statistics yields a p-value of 0.013, indicating statistical significance. Referring to Pesaran's critical value bounds (Case III: intercept and no trend) with k = 2, the upper bound at the 95% confidence level is 4.85, and the lower bound is 3.75. The observed F-statistics of 5.3085 exceeds the upper bound, confirming co-integration. Since the ARDL approach tests for linear co-integration, these results support a linear long-run relationship between domestic CPO price and production, consistent with classical supply theory (Encyclopaedia Britannica 2019), which posits an upward-sloping supply curve where price and quantity supplied rise proportionally. Specifically, a 10% increase in quantity supplied corresponds to an approximately proportional increase in price along this linear supply curve.

The results summarized in Table 7 corroborate the ARDL findings, indicating a symmetric relationship. However, the NARDL model demonstrates a more robust fit, given its higher 99% confidence level compared to the ARDL model's 95% confidence level (Akca & Kaya 2023). Accordingly, the NARDL framework better captures the dynamic and potentially asymmetric nature of the relationship between domestic CPO price and production.

Table 8 provides strong support for the hypothesis regarding long-run effects, as reflected by the positive (+) and negative (−) coefficients. The results indicate that changes in domestic CPO price range from approximately +0.845 to −0.808. Specifically, a 1% rise in CPO production corresponds to a roughly 0.808% rise in price, whereas a 1% decrease in production is associated with a roughly 0.845% decrease in price. The closeness of these coefficients (roughly ±0.8) indicates a symmetric long-run relationship, visually confirmed in Figure 1(a), which illustrates the long-term co-movement between the variables.

Conversely, Figure 1(b) reveals evidence of asymmetric short-run dynamics, particularly within the first six months following a shock. During this period, deviations from equilibrium in CPO production or price display persistent negative effects before gradually reverting to a symmetric and linear relationship after approximately six to ten months. These observations are consistent with classical supply theory, which posits a positively sloped supply curve reflecting the direct relationship between price and quantity supplied (Shapiro 2024).

TABLE 5 (a). Summary of Engle-Granger test using seven variable

T-Statistic	Highest AIC	Highest SBC
-7.0213	39.9032	38.9372

TABLE 5 (b). Summary of Engle Granger test using six variable

T-Statistic	Highest AIC	Highest SBC	Critical Value
-5.7303	64.5110	63.5354	-5.0382

TABLE 5 (c). Johansen co-integration test result with unrestricted intercepts and restricted trends

Co-integration Long Run Test Based on Maximal Eigenvalue of the Stochastic Matrix				
Null	Alternative	Statistic	95% Critical Value	90% Critical Value
r=0	r=1	99.3316	49.3200	46.5400
r<1	r=2	34.1643	43.6100	40.7600
Co-integration Long Run Test Based on Base on Trace of the Stochastic Matrix				
Null	Alternative	Statistic	95% Critical Value	90% Critical Value
r=0	r=1	202.4146	147.2700	141.8200
r<1	r=2	103.0830	115.8500	110.6000
Null	Alternative	Statistic	95% Critical Value	90% Critical Value

TABLE 6. Autoregressive distributive lags co-integration result on the domestic CPO price and domestic CPO production

Statistics	CHSQ/ F-statistic	p-value
Langrange Multiplier (CHSQ)	17.2519	0.000
Likelihood Multiplier (CHSQ)	20.8711	0.000

TABLE 7. Non-Linear Autoregressive Distribute Lags Co-Integration- Domestic CPO Price Versus Domestic CPO Production[1]

t_BDM Statistic	F_PSS Statistic	Conclusion
-2.3978	2.5172	Long run symmetry co-integration

TABLE 8. Asymmetric statistic on non-linear autoregressive distributive lags long-run effect between domestic cpo price and production

Co-efficient	F-statistic	P>F	Decision	Conclusion
Long-run Effect [+]				
-0.808	1.976	0.166	Accept null	Long run symmetry
Long-run Effect [-]				
0.845	2.218	2.218	Accept null	Long run symmetry

TABLE 9. Non-linear autoregressive distributive lags asymmetry relation- domestic CPO price versus domestic CPO production[2]

F-statistic	P>F	Decision	Conclusion
Long-Run Asymmetry			
0.09031	0.765	Accept the null	Long run symmetry
Short-Run Asymmetry			
4.61	0.037	Reject the null	Short run asymmetry

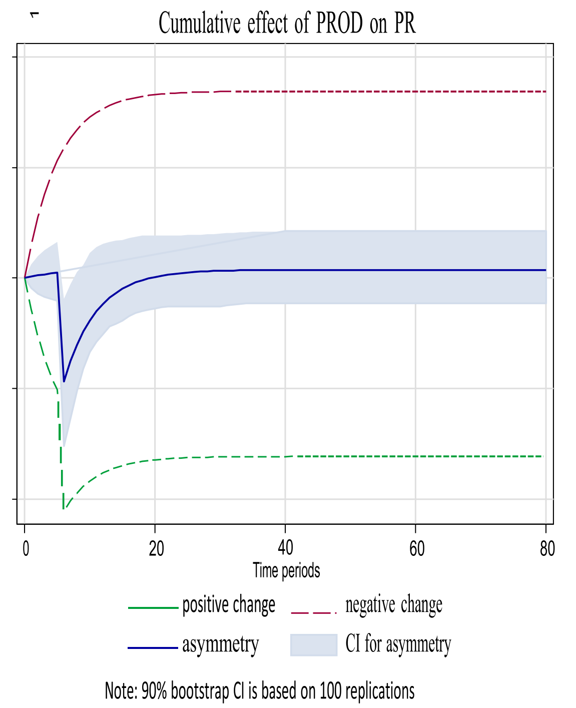

FIGURE 1(a). Long-term co-movement between the variables

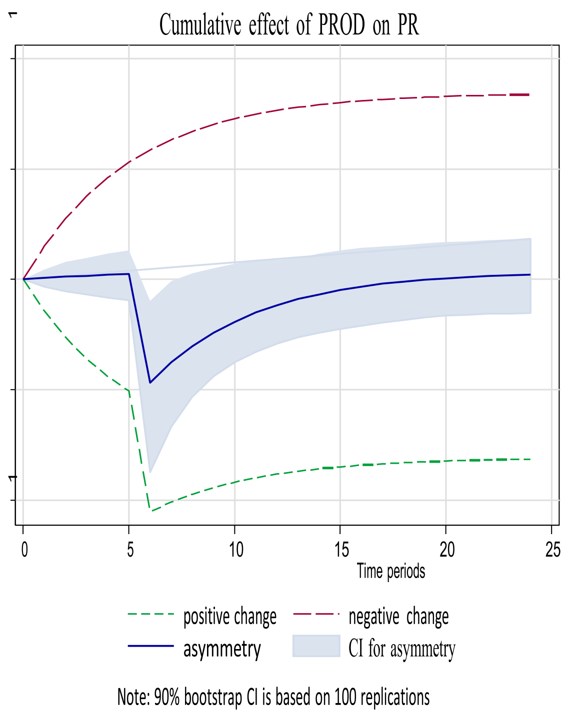

FIGURE 1(b). Asymmetric short-run dynamics

LONG-RUN STRUCTURAL MODEL (LRSM)

The LRSM results, shown in Table 10, reveal that domestic CPO production (Bahar et al. 2023), CPO export price and volume (Huda & Sidiq 2023), and the CPI (Rizal et al. 2023) have statistically significant impacts on domestic CPO prices. These results align with both economic theory and previous empirical studies, though further theoretical interpretation warranted. Interestingly, inflation does not appear statistically significant, which calls for closer scrutiny. This may be because inflation primarily affects the exchange rate and, in turn, import demand rather than export demand. Given that export demand drives both CPO export prices and domestic prices, the lack of significance for inflation indicates that it plays a limited direct role in determining domestic CPO price movements.

To validate this interpretation, robustness tests were conducted by imposing over-identifying restrictions that exclude the variable inflation from the model. The results, presented in Table 11, show that CPO export price and volume, together with CPI, remain significant determinants influenced by domestic CPO price. These findings highlight export price and volume, along with CPI, as key drivers of the long-run behavior of domestic CPO prices. Specifically, increases in export price and volume are associated with higher domestic prices, whereas decreases in the consumer price index correspond with declines in domestic CPO prices.

TABLE 10. The long run structural model (LRSM) - Exact identification

Variance	Co-efficient	Standard Error	T-Ratio	Implication
LPR	1.0000	-	-	-
LPROD	-.3001E-3	(6640E-4)	4.5296	Significant
LTXPORT	-.084348	(.051547)	1.6195	Insignificant
LRMXPORT	-.018286	(.0067232)	2.7198	Significant
LPXPORT	-1.8494	(.20936)	8.8336	Significant
LINF	-.022892	(.024463)	0.9358	Insignificant
LCPI	8.6955	(2.8989)	2.9996	Significant
Trend	-.018172	(.0062928)	2.8877	Significant

Note: t-ratio in absolute figure

TABLE 11. The long run structural model (LRSM) – Over-identification

Variable	Co- efficient	StandardError	T-Ratio	Reject/ Accept Null	Implication
LPR	-	-	-	-	-
LPROD	-.11098	(0.010489)	10.5086	Reject Null	Restriction false
LTXPORT	-.0079503	(.023428)	0.3394	Accept Null	Restriction correct
LRMXPORT	-.0028575	(.0031633)	0.9033	Accept Null	Restriction correct
LPXPORT	-1.3051	(.079003)	16.5196	Reject Null	Restriction false
LINF	-	-	-	-	-
LCPI	1.1269	(.78222)	1.4406	Accept Null	Restriction correct
Trend	-.0022713	(.0016898)	1.34412	Accept Null	Restriction correct

Note: t-ratio in absolute figure and chi-square statistic is 0.20280[.652]

VECTOR ERROR CORRECTION MODEL (VECM)

The examination identifies a strong and statistically significant co-integration relationship between domestic CPO price and domestic CPO production. However, the co-integrating equation alone does not reveal the direction of causality, that is, which variable acts as the leader and which as the follower. To address this, Table 12 presents the VECM results, which classify variables as endogenous or exogenous based on their dynamic interactions within the system.

A key finding from Table 12 is that the domestic CPO price functions as the dependent (endogenous) variable, while other variables, including domestic production volume, export volume, export turnover, export price, inflation, and the Consumer Price Index (CPI), are identified as exogenous factors. This classification aligns with economic theory, which typically treats price as the dependent variable in commodity markets such as crude palm oil. The statistical significance of price as an endogenous variable is confirmed by a highly significant t-test (p-value = 0.000), indicating strong confidence in this role.

Furthermore, the exogenous status of production, export-related variables, inflation, and CPI suggests that shocks to these factors exert direct and measurable impacts on domestic CPO price dynamics. This observation provides a more nuanced understanding that challenges the simplistic notion of price as merely reactive, highlighting instead the complex interdependencies among the system's variables.

The error correction term coefficient, ecm1(-1), represents the rate at which the system returns to its long-run equilibrium following a shock. For example, the coefficient for domestic CPO price is −0.94651, showing that approximately 95% of any departure from equilibrium is restored within one month, demonstrating a rapid adjustment. Among the explanatory variables, domestic CPO production (coefficient: 213.887) adjusts the slowest, while the CPI responds the fastest, highlighting the distinct dynamic behaviors of these variables within the system.

TABLE 12. Vector error correction model (VECM) on variables

ecm1(-1)	Co-efficient	Standard Error	T-Ratio (Probability)	Result
dLPR	-.94651	.13017	-7.2711[.000]	Endogenous
dLPROD	-213.8668	477.9478	-.44747[.656]	Exogenous
dLTXPORT	.10392	.60667	.17130[.865]	Exogenous
dLRMXPORT	-.30782	4.1887	-.073488[.942]	Exogenous
dLPXPORT	.043104	.092279	.46711[.642]	Exogenous
dLINF	.10164	.72814	.13958[.890]	Exogenous
dCPI	-.0084785	.0060334	-1.4053[.166]	Exogenous

VARIANCE DECOMPOSITION (VDC)

The VECM identifies the average domestic price of CPO as an endogenous variable within the time series framework, which constitutes a significant finding. However, the relative exogeneity of the remaining variables warrants further examination. Specifically, it remains unclear which variables exhibit the greatest or least lag in response to shocks relative to others. Since the VECM does not provide this distinction, variance decomposition (VDC) analysis is employed to elucidate the relative degrees of exogeneity and endogeneity among the variables.

In practice, VDC separates the forecast error variance of each variable into components attributable to shocks from all variables within the system, rather than just its own past values. Variables whose forecast error variance primarily explained by their own historical values considered exogenous, while those influenced by other variables deemed more endogenous. The VDC results for this study presented in Tables 13(a), (b), and (c), as well as Tables 14(a), (b), and (c). To facilitate comparison between short-run (up to 12 months) and long-run (beyond 12 months) dynamics, 12- and 24-month horizons selected. Tables 13(a) and 13(b) display the decomposition of each variable's forecast error variance (expressed in percentages) into contributions from its own shocks and from other variables, with rows and columns representing the respective variables. The diagonal elements, highlighted in blue, show the share of variance attributable to each variable's own shocks, reflecting its relative exogeneity. Table 13(c) provides a summary of these results, ranking the variables according to their degree of exogeneity based on the generalized variance decomposition.

At first glance, the results may appear counterintuitive; however, they reaffirm that the domestic CPO price is the least exogenous, that is the most endogenous, variable in the system, consistent with the VECM findings. The ranking of variables remains stable across both the 12- and 24-month horizons, indicating robustness over time. Notably, inflation emerges as the most exogenous factor, aligning with its broad and pervasive influence on overall economic activity. Although inflation does not directly affect the domestic CPO price in this context, its economy-wide impact renders it relatively exogenous. The CPI occupies an intermediate position between domestic CPO production and total export turnover, consistent with its role in influencing overall domestic output and aggregate demand.

Focusing on the key variables of interest—domestic CPO production and domestic CPO price, the findings further corroborate the VECM results: domestic CPO price is endogenous, while domestic CPO production is exogenous. This relationship underscores that domestic production acts as the primary driver of domestic CPO price movements (Sulistyanto & Akyuwen 2011), whereas other variables exert comparatively weaker direct influences.

In contrast, the orthogonalized VDC produces different results due to its inherent methodological limitations. This method assumes that all other variables held constant ("switched off") when measuring the impact of shocks to a specific variable. Additionally, the outcomes depend on the ordering of variables in the VAR system, meaning the results are not unique and may vary with different orderings. Figure 2 depicts the relationship between the most exogenous and endogenous variables, while Table 13(b) presents the 24-month orthogonalized VDC results and Table 13(c) summarizes the overall rankings. Compared with the generalized variance decomposition, the orthogonalized VDC identifies total CPO export tonnage as the most exogenous variable, followed by inflation, whereas the export price of CPO is the most endogenous (Figure 3). Notably, price-related variables consistently exhibit lower exogeneity under this approach. Inflation remains the most exogenous factor (Chik et al. 2023; Samwel & Khinsa 2023), followed by domestic CPO price, with export CPO price being the most endogenous.

Despite these differences, the generalized variance decomposition results, where both domestic and export CPO prices exhibit endogeneity are consistent with the VECM findings (Henindar & Sari 2020). This consistency reinforces the robustness of the conclusion that domestic CPO price is endogenous within the system, driven primarily by shocks originating from production and external trade variables.

TABLE 13(a). Generalized variance decomposition - 12 month time horizon

	LPR	LPRD	LTXPORT	LRMXPORT	LPXPORT	LINF	LCPI
LPR	39.07%	48.21%	0.01%	0.54%	44.41%	0.74%	3.39%
LPROD	0.61%	95.61%	0.01%	0.01%	4.70%	0.02%	0.09%
LTXPORT	0.10%	0.02%	99.90%	30.52%	0.00%	0.01%	3.28%
LRMXPORT	0.47%	0.29%	30.01%	99.83%	0.05%	0.04%	0.01%
LPXPORT	63.62%	0.77%	0.01%	0.01%	99.84%	1.38%	7.22%
LINF	0.67%	0.27%	0.01%	0.04%	1.59%	99.93%	28.15%
LCPI	1.26%	3.33%	2.78%	0.01%	9.32%	26.88%	98.27%

TABLE 13(b). Generalized variance decomposition – 24-month time horizon

	LPR	LPRD	LTXPORT	LRMXPORT	LPXPORT	LINF	LCPI
LPR	39.06%	48.19%	0.01%	0.55%	44.69%	0.74%	3.42%
LPROD	0.63%	95.45%	0.01%	0.00%	4.91%	0.02%	0.05%
LTXPORT	0.11%	0.02%	99.90%	30.53%	0.00%	0.01%	3.28%
LRMXPORT	0.48%	0.30%	30.00%	99.82%	0.05%	0.04%	0.01%
LPXPORT	63.65%	0.79%	0.01%	0.01%	99.84%	1.38%	7.22%
LINF	0.67%	0.27%	0.01%	0.04%	1.60%	99.93%	28.16%
LCPI	1.27%	3.37%	2.77%	0.00%	9.37%	26.87%	98.26%

TABLE 13(c). Generalized variance decomposition of the variable's ranking according to monthly time horizon

Ranking	At Horizon 12 Month	At Horizon 24 Month
1	LINF	LINF
2	LTXPORT	LTXPORT
3	LPXPORT	LPXPORT
4	LRMXPORT	LRMXPORT
5	LCPI	LCPI
6	LPRD	LPRD
7	LPR	LPR

TABLE 14(a). *Orthogonalized* variance decomposition in 12 month-time horizon

	LPR	LPRD	LTXPORT	LRMXPORT	LPXPORT	LINF	LCPI
LPR	39.07%	49.47%	0.03%	0.13%	11.22%	0.02%	0.06%
LPROD	0.61%	95.42%	0.01%	0.05%	3.89%	0.01%	0.02%
LTXPORT	0.10%	0.02%	99.85%	0.00%	0.02%	0.00%	0.00%
LRMXPORT	0.47%	0.31%	29.91%	69.28%	0.03%	0.00%	0.00%
LPXPORT	63.62%	0.58%	0.11%	0.08%	35.60%	0.00%	0.00%
LINF	0.67%	0.28%	0.00%	0.02%	1.12%	97.91%	0.00%
LCPI	1.26%	3.39%	2.76%	1.71%	13.84%	22.40%	54.64%

TABLE 14(b). *Orthogonalized* variance decomposition in 24 month time horizon

	LPR	LPRD	LTXPORT	LRMXPORT	LPXPORT	LINF	LCPI
LPR	39.06%	49.47%	0.03%	0.13%	11.22%	0.02%	0.06%
LPROD	0.63%	95.24%	0.01%	0.05%	4.03%	0.01%	0.02%
LTXPORT	0.11%	0.02%	99.86%	0.00%	0.02%	0.00%	0.00%
LRMXPORT	0.48%	0.31%	29.91%	69.28%	0.03%	0.00%	0.00%
LPXPORT	63.65%	0.59%	0.11%	0.08%	35.57%	0.00%	0.00%
LINF	0.67%	0.29%	0.00%	0.02%	1.13%	97.90%	0.00%
LCPI	1.27%	3.43%	2.76%	1.70%	13.92%	22.37%	54.56%

TABLE 14(c). Generalized variance decomposition of the variable's according ranking according

Ranking	In Horizon 12 Month	In Horizon 24 Month
1	LTXPORT	LTXPORT
2	LINF	LINF

3	LPRD	LPRD
4	LRMXPORT	LRMXPORT
5	LCPI	LCPI
6	LPR	LPR
7	LPXPORT	LPXPORT

FIGURE 2 . *Exogeneity* relation on the factors of crude palm oil model base on generalized variance decomposition technique

FIGURE 3. *Endogeniety* relation on the factors of crude palm oil model base on *orthogonalized* variance decomposition technique

IMPULSE RESPONSE FUNCTIONS (IRF)

Like the variance decomposition analysis, the IRF provides complementary insights by visually illustrating the dynamic effects of shocks over time. Figures 4 and 5 present the IRF results over long (60 months) and short (8 months) horizons, respectively, demonstrating how a shock to one variable, such as inflation, propagates through the system and influences other variables.

As shown in Figure 4, shocks to crude palm oil (CPO) production volume and domestic CPO prices exhibit distinct short-term dynamic responses. Domestic CPO prices react almost immediately, beginning their adjustment within a relatively short period, whereas CPO production responds with a slight lag. Despite these initial differences, both variables eventually converge toward equilibrium, confirming the system's long-run stability (Innocenti 2024). Notably, the short-run relationship between CPO production and domestic prices appears non-linear and asymmetric, but it gradually evolves into a linear and symmetric pattern over the medium to long term. These findings are consistent with prior studies suggesting that the long-run interaction between these variables is both symmetric (Salami & Haron 2018) and linear (Limbong & Halimatussadiah 2022; Norhidayu et al. 2017).

Figure 5 focuses on a shorter horizon of eight months, offering deeper insight into the speed and intensity of these adjustments. Shocks to CPO production have the most pronounced effect within the first two months and require approximately five and a half months to return to equilibrium. In contrast, domestic CPO prices reach their peak within the first two months but stabilize more quickly, within less than four and a half months. This pattern suggests that domestic CPO prices are more flexible and adjust more rapidly to external shocks than production levels, which are constrained by physical and structural factors such as planting cycles, harvesting schedules, and processing capacities.

Overall, the IRF analysis confirms that domestic CPO prices respond more rapidly and stabilize faster than domestic production following shocks, consistent with theoretical expectations for commodity markets, where prices typically serve as the primary adjustment mechanism in the short run.

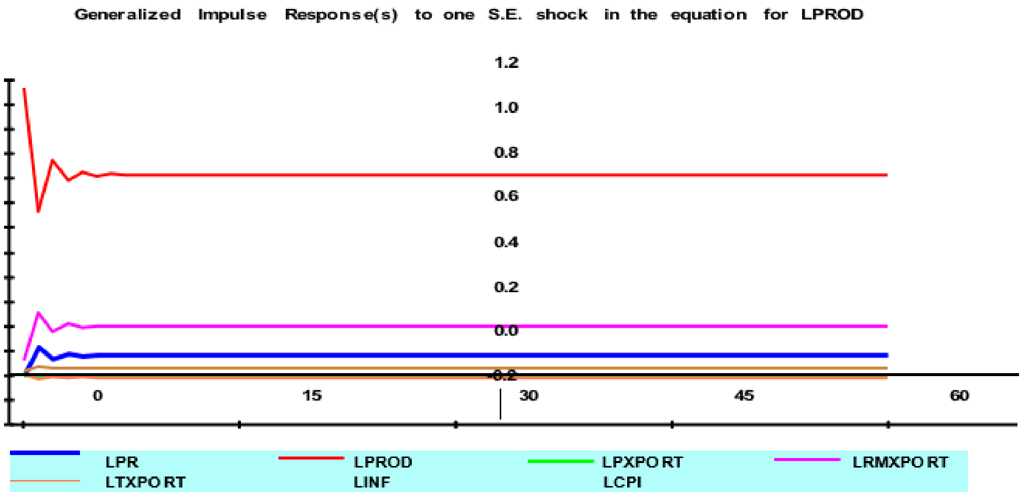

FIGURE 4 : The dynamic effects of shocks over 60 month time horizon

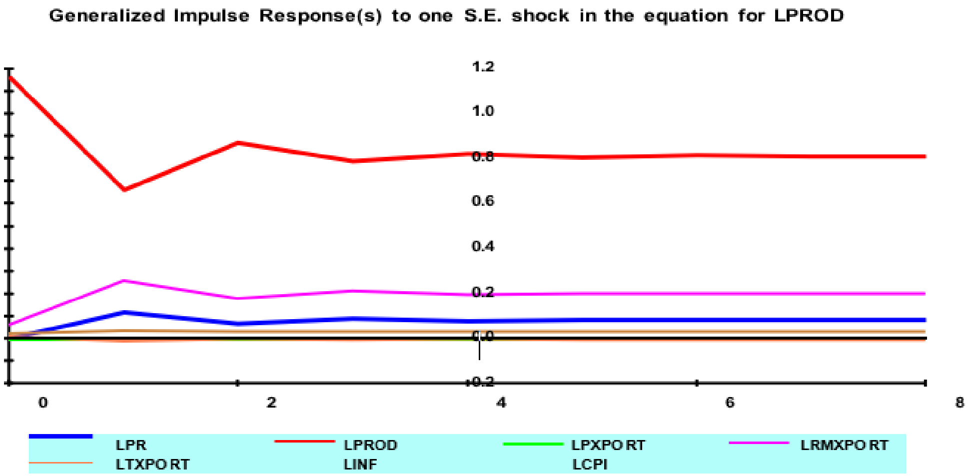

FIGURE 5: The dynamic effects of shocks over eight month time horizon

PERSISTENCE PROFILE

The Persistence Profile (PP) provides valuable insights into the temporal dynamics of how a system-wide shock affects the cointegrated equilibrium, complementing the variable-specific insights derived from Impulse Response Functions (IRFs). While IRFs assess the effects of shocks to individual variables on the rest of the system, the PP focuses on the system's collective adjustment back to equilibrium following a generalized disturbance.

As illustrated in Figure 6, which presents the persistence profile over a 60-month horizon, the cointegrated variables exhibit coordinated movement toward equilibrium after experiencing external shocks—such as policy interventions, exchange rate volatility, or fluctuations in global derivative markets (Keswani et al. 2024; Oluranti et al. 2024). The profile indicates that the system returns to its long-run equilibrium within approximately seven months. A short-term view in Figure 7 further supports this finding, showing a sharp initial decline in the persistence value from 1.0 to 0.2 during the first month, followed by gradual convergence by the third month. These results suggest that external shocks exert only temporary and limited effects on the long-run dynamics of the Malaysian palm oil industry, thereby underscoring the system's inherent stability and resilience (Hidayat et al. 2023; Sahara et al. 2022; Rifn et al. 2020).

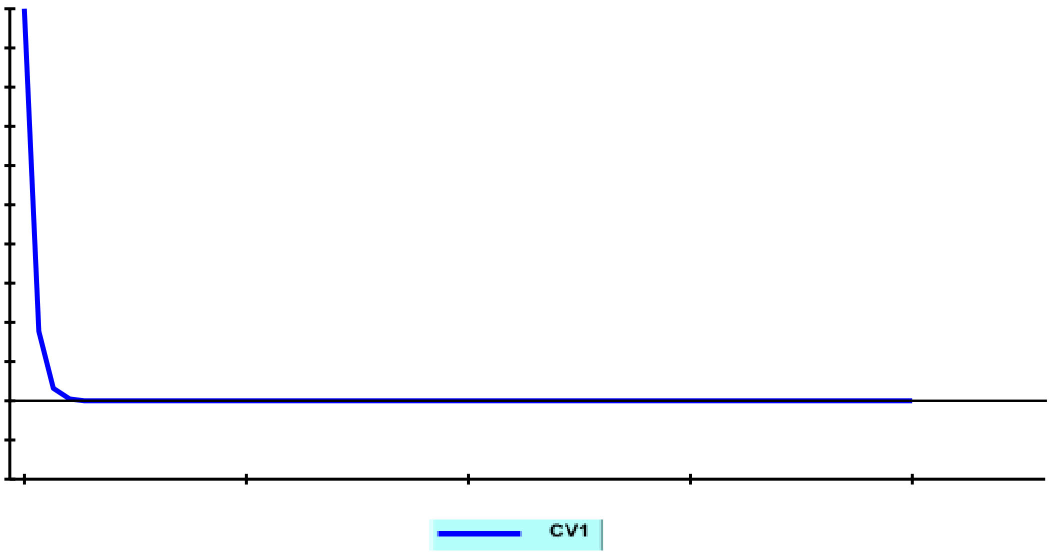

FIGURE 6: The persistence profile over 60 month horizon

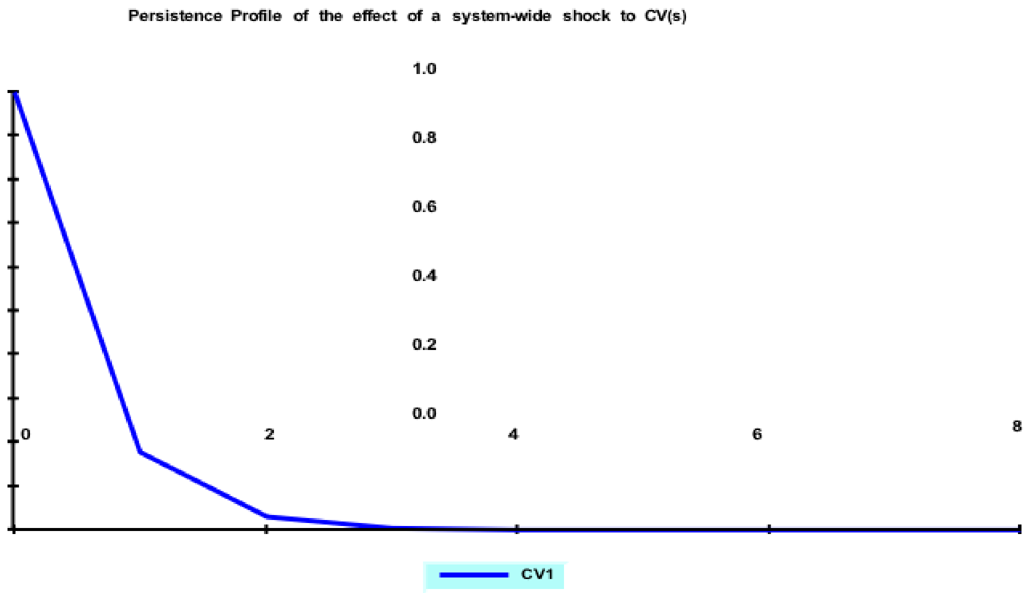

FIGURE 7: The persistence profile over 8 month horizon

SUMMARY FINDINGS AND DISCUSSIONS

As overall, the key findings of this research in relation to the research questions (RQs) are as follows:

- RQ_1 There exists a linear cointegration relationship between domestic crude palm oil (CPO) price and domestic CPO production, confirming the long-run equilibrium linkage between the two variables (Encyclopaedia Britannica, 2019).
- RQ_2 In the long run, domestic CPO price and production demonstrate a symmetric and linear relationship (Shapiro 2024; Limbong & Halimatussadiah 2022; Norhidayu et al. 2017). However, in the short run, these variables move asymmetrically and non-linearly, deviating temporarily from equilibrium before returning to it within a short adjustment period (Innocenti 2024).
- RQ_3 A causal relationship is identified whereby domestic CPO production acts as the leader, and domestic CPO price functions as the follower. This finding represents a novel empirical contribution that contradicts classical supply theory, which traditionally positions price as the leading determinant of production.
- RQ_4 Domestic CPO production, export volume, and the CPI exert a significant influence on domestic CPO price, highlighting the multifaceted drivers of price dynamics in the palm oil market (Bahar et al. 2023; Huda & Sidiq 2023; Rizal et al. 2023).
- RQ_5 Inflation is identified as the most exogenous variable in the system, while domestic CPO price is the least exogenous, implying that the latter is highly responsive to both domestic and external shocks (Chik et al. 2023; Samwel & Khinsa 2023; Henindar & Sari 2020).
- RQ_6 Disturbances arising from exogenous shocks to domestic CPO production are most pronounced within the first two months, with equilibrium restoration occurring around the sixth month. In contrast, domestic CPO prices adjust more rapidly, beginning to stabilize within two months and reaching equilibrium by approximately the fourth month.
- RQ_7 The cointegrated variables exhibit coordinated movement following external shocks, with the overall system typically returning to equilibrium within three months or more. These shocks exert limited and statistically insignificant long-term effects on the stability of the palm oil industry, confirming the system's resilience (Hidayat et al. 2023; Sahara et al. 2022; Rifn et al. 2020).

CONCLUSION AND POLICY IMPLICATIONS

The most significant finding of this research is the identification of a linear and symmetric relationship between domestic CPO price and domestic CPO production. This result challenges classical economic theory by demonstrating that production (supply) primarily determines price, rather than the reverse. Furthermore, variance decomposition analysis reveals that inflation is the most exogenous factor, shaped by a wide range of domestic and international forces beyond direct sectoral control. Conversely, the CPI appears to be more domestically driven, exerting a direct influence on domestic CPO production. Crucially, domestic CPO production exerts a direct and significant impact on domestic CPO price, whereas the domestic CPO price is identified as the least exogenous variable, indicating that price does not exert a determining influence on production levels. Collectively, these findings yield several important policy implications for enhancing the resilience and efficiency of Malaysia's CPO sector.

First, the identification of domestic CPO production as the causal determinant of price movements underscores the importance of proactive supply-side management. Policymakers should prioritize monitoring and stabilizing production through strategic interventions, including weather-based insurance schemes, productivity enhancement programs, and sustainable land-use planning. Such measures would mitigate the effects of production shocks and help reduce volatility in domestic pricing (Hidayat et al. 2024; Bahar et al. 2023; Ismail et al. 2022).

Second, the existence of short-run asymmetry and volatility in price responses to production shocks highlights the need for buffer stock mechanisms or price stabilization funds. These instruments could act as automatic stabilizers, cushioning temporary supply–demand mismatches and preventing speculative market distortions that disproportionately affect producers and consumers (Innocenti 2024; Akca & Kaya 2023; Suharsono et al. 2023).

Third, the finding that export price and volume significantly influence domestic CPO prices calls for a recalibration of Malaysia's export strategy. Diversification into non-traditional export markets and the negotiation of bilateral trade agreements would reduce exposure to external demand shocks. Moreover, developing value-added downstream CPO derivatives can enhance export revenues while simultaneously reducing inflationary pressure on domestic CPO prices (Ramli & Ahmad 2024; Bahar et al. 2023; Huda & Sidiq 2023).

Although inflation is identified as the most exogenous factor, its indirect effects through cost-push pressures and exchange rate transmission mechanisms remain significant. Consequently, macroeconomic stability, particularly through monetary–fiscal policy coordination, is crucial to ensuring that inflation does not undermine the international competitiveness or domestic affordability of palm oil products (Chik et al. 2023; Samwel & Khinsa 2023; Henindar & Sari 2020).

The study also finds that the system returns to equilibrium relatively quickly, within three to seven months, following exogenous shocks. However, the existence of a vulnerability window of approximately two months suggests the need for real-time monitoring systems and early-warning indicators. These mechanisms should track variables such as climatic anomalies, labour constraints, and international commodity trends to enable timely policy responses (Hidayat et al. 2023; Sahara et al. 2022; Rifn et al. 2020).

The establishment of a long run cointegrated relationship between domestic CPO price and production also provides a foundation for formulating long-term agricultural development strategies. Agencies such as the Federal Land Development Authority (FELDA) and the MPOB are encouraged to focus on sustainable replanting programs, mechanization projects, and yield optimization initiatives to reinforce the structural supply base of the palm oil industry (Abdullah et al. 2022; Bahar et al. 2023; Razak et al. 2021).

Furthermore, the evidence of system-wide co-movement among key CPO market variables such as exports and consumer prices illustrates the interdependence of economic sectors. This finding reinforces the need for inter-ministerial coordination, particularly among the ministries responsible for agriculture, trade, finance, and energy, to formulate cohesive and mutually reinforcing policies that maintain systemic equilibrium (Hashim et al. 2023; Yusuf et al. 2022; Tan et al. 2021).

Finally, given that domestic CPO prices are endogenous and highly sensitive to both internal and external shocks, there is a strong rationale for investment in advanced price transmission modeling and policy simulation tools. Such analytical capabilities would enable more accurate forecasting of price dynamics and support data-driven policymaking to protect the interests of smallholders, processors, and consumers across the domestic CPO value chain (Rahman et al. 2023; Khalid et al. 2022; Tan et al. 2021).

LIMITATION OF THE STUDY AND SUGGESTION FOR FUTURE STUDY

This study concentrates on a limited set of variables, namely domestic CPO production and price, export volume and price, inflation, and the CPI. Nonetheless, other factors could also significantly influence CPO quantity and pricing, including labor costs, prices in competing countries, technological innovations in CPO production, and transportation expenses. The omission of these variables represents a limitation that future research should address.

Additionally, incorporating insights from key stakeholders, such as policymakers, producers, processors, and exporters—could provide valuable contextual understanding of market dynamics, linking quantitative findings to real-world industry conditions. Therefore, future studies are encouraged to employ mixed-method or qualitative approaches, for example expert interviews or focus group discussions, to gain deeper insights into the determinants of supply and demand in the CPO market and to complement econometric analyses with practical, industry-based perspectives.

NOTES

[1] The bound test of the long-run asymmetry at k=2, is rejected (below lower bound).

[2] Long run bound test at k=2, is at upper bound condition base on Pesaran *et.al* (2001) in Mansor (2017: 14)

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Mohd Abdul Hamid Hashim*
Faculty of Business
UNITAR International University
Tierra Crest, Jalan SS 6/3, SS 6
47301 Petaling Jaya, Selangor, MALAYSIA.
E-mail : mohdabdulhamidbinhashim@gmail.com.

Nik Hasfizul Hassan
Faculty of Business
UNITAR International University
Tierra Crest, Jalan SS 6/3, SS 6
47301 Petaling Jaya, Selangor, MALAYSIA.
E-mail: nikhasfizul.safuri@unitar.my

*Corresponding author