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Market integration analysis between crude palm oil (CPO) prices in the international market and fresh fruit bunch (FFB) prices at the farmgate market

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Abstract

The welfare of independent oil palm farmers remains highly dependent on the transmission of fresh fruit bunch (FFB) prices at the provincial level and on crude palm oil (CPO) prices on the international market. In Indonesia, several provinces produce the largest FFB and Riau is the province that produces the largest FFB in Indonesia, so it is often used as a reference for FFB prices in other provinces in Indonesia. This research aimed to analyze market integration by examining the transmission of FFB prices at the smallholder farmer level in Riau Province, considering FFB prices at the provincial level and CPO prices in the international market. This research used monthly time series data from 2015 to 2023 and analyzed using the Vector Error Correction Model (VECM) methodology. The study indicates price asymmetry in FFB at the farmer level, where farmers face negative long-term impacts from CPO price increases and slower short-term responses to provincial prices compared to international prices, reflecting imbalanced domestic price transmission. Provincial and district/city governments need to strengthen the FFB price determination mechanism at the farmer level by strictly supervising the alignment of palm oil mill prices with provincial reference prices to reflect domestic and international CPO price dynamics better.

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Introduction

The palm oil industry plays an important role in the Indonesian economy. Palm oil is produced from FFB of palms. Palm oil, derived from fresh fruit bunches (FFB) of oil palm (*Elaeis guineensis*), is a crucial raw material for producing CPO and palm kernel oil (PKO). Each FFB consists of small, oil-rich fruits containing high oil content in both the pulp (mesocarp) and kernel (seed). CPO and PKO together supply most of the world's vegetable oils (Suttayakul et al., 2016). The CPO industry plays a key role in meeting global vegetable oil demand, given its high yield and cost-efficiency compared to other vegetable oils. The palm oil industry has a *multiplier effect* in rural areas outside oil palm plantations, namely, the (1) financial services sector; (2) financial assistance services; (3) trade, restaurants, and hotels; (4) chemical, fertilizer and pesticide industries; (5) oil, gas, and mining; (6) transportation; (7) infrastructure; (8) food industry; (9) machinery and electricity; and (10) other sectors (Amzul 2011). The results of the study on the impact of oil palm plantations on villages and non-oil palm found that there was an increase in social, economic, and ecological progress in various oil palm village communities (Nasdian et al., 2022).

As the world's leading CPO producer, Indonesia exports large volumes of palm oil to meet global demand for food, cooking oil, and bioenergy industries (Dharmawan et al., 2021). Indonesia exported around 56 percent of palm oil to the world market in 2023 (Figure 1). Indonesia's domestic demand for CPO has surged, driven by its use in the food, cosmetics, chemical, pharmaceutical, and bioenergy industries (Rosita et al., 2014). The development of palm oil-based biodiesel which began production in 2006, also drove an increase in the need for CPO. Rapid growth in palm biodiesel production could further escalate CPO demand, potentially creating a trade-off for other industries, including cooking oil production. Rising CPO prices may also increase FFB prices, influencing production trends (Joni et al., 2011; Nuva et al., 2019).

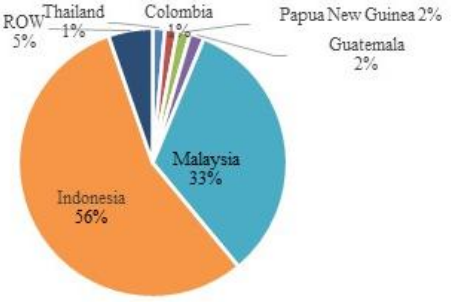


Figure 1 Market share of palm oil exporting countries in 2023

Adapted from Indexmundi, processed

Despite Indonesia's global palm oil industry dominance, price volatility remains a persistent challenge, especially for smallholders (Hendrawan et al., 2024).

Palm oil farmers often face price asymmetry, where global price fluctuations are not proportionally reflected in the prices they receive for FFB. They also tend to have difficulty to access markets (Vamuloh et al., 2020). Price transmission is critical in the agricultural sector as it links farmgate prices to downstream market prices observed in processing, wholesale, or retail markets. Transmission of agricultural commodity prices can be caused by trade liberalization policies (Olipra, 2020). Analyzing this process helps evaluate how external price fluctuations, market interventions, and value chain dynamics affect farmers' livelihoods.

The palm oil sector is a cornerstone of Indonesia's economy, providing employment and livelihoods for millions. In 2020, the number of farmers in the oil palm sector reached 2,558,741 farmers (Vintarno et al., 2019). In Riau Province, Indonesia's largest palm oil-producing region, the oil palm plantation area reached 2.86 million hectares in 2022, producing 8.74 million tons of CPO and employing 548,005 workers in 2021 (Badan Pusat Statistik Provinsi Riau, 2024). Smallholder farmers, who typically own less than 20 hectares of oil palm plantations, account for a substantial share of production in this region.

Despite their contributions, smallholder farmers often operate as price takers due to their limited bargaining power, which prevents them from securing favourable prices for their FFB. This imbalance in bargaining power is a primary driver of unfair trade practices (Russo et al., 2023). The regulation of FFB pricing in Indonesia, as outlined in the Minister of Agriculture Regulation Number 01/PERMENTAN/KB.120/1/2018, aims to address these disparities by linking FFB prices to CPO market dynamics. However, challenges persist, with studies showing that palm oil and FFB prices are closely interrelated (Charoenrit et al., 2021) and that CPO price margins are significantly influenced by FFB prices (Syahril et al., 2020). Addressing these issues is essential for ensuring equitable growth, supporting smallholder welfare, and sustaining Indonesia's vital palm oil industry.

However, after reaching its peak, FFB prices experienced a sharp decline in mid-2022, most likely caused by the CPO export ban policy implemented by the Indonesian government. This policy caused a buildup of CPO stocks domestically and directly impacted on FFB prices at the farmer level. After this decline, prices began to recover gradually but continued to

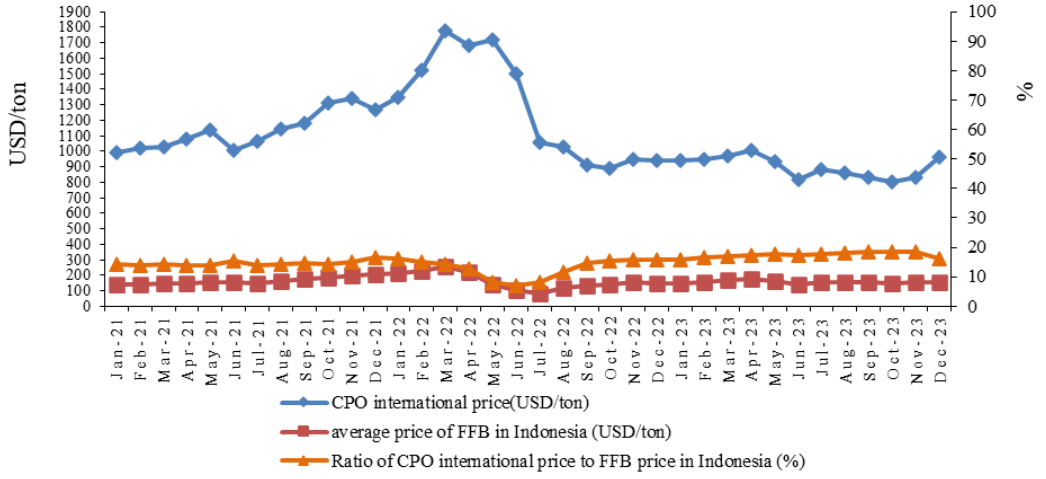


Figure 2 CPO prices on the international market and their ratio to FFB prices in Indonesia 2021–2023

show volatility until the end of 2023, with prices tending to be more stable than the previous period.

Adapted from Index Mundi, Ministry of Agriculture, and APKASINDO

Figure 2 shows that while international CPO prices fluctuated sharply from 2021–2023, FFB prices in Indonesia remained relatively stable, highlighting incomplete price transmission to farmers. The CPO to FFB price ratio exceeded 50 percent during the CPO price surge, reflecting inefficiencies in price transmission. Market integration analysis plays a critical role in economic policy formulation, especially for commodities such as palm oil that are heavily traded in the international market (Lyu et al., 2023; Yang, 2023; Zhao et al., 2021). The relationship between international CPO prices, domestic CPO prices, and FFB prices received by independent smallholders determines the effectiveness of the price transmission mechanism. If market integration is weak, smallholders may be disproportionately affected by market distortions, limiting their ability to benefit from price increases while remaining vulnerable to price declines. Weak market integration has left smallholders vulnerable to price drops and restricted their ability to benefit from price increases.

Despite Indonesia's global palm oil industry dominance, price volatility remains a persistent challenge, especially for smallholders (Hendrawan et al., 2024). This study analyzes the price integration between international, domestic, and smallholder FFB prices in Riau Province using the Vector Error Correction Model (VECM). The findings aim to guide policymakers in designing strategies for market stabilization, smallholder price protection, and sustainable agribusiness while anticipating global market shocks to improve proactive policy responses.

Research Method

Data Collection

The data used in this research are secondary time series data in the form of monthly data from January 2015 to December 2023. Time series data are expected to identify price fluctuation patterns and the relationship between global CPO prices and FFB prices at the farmgate level. Monthly FFB prices at the farmer level were collected from The Indonesian Palm Oil Farmers Association (Asosiasi Petani Kelapa Sawit Indonesia/APKASINDO), and Amanah Association while monthly FFB prices at the provincial level were from Riau Provincial Plantation Office (Dinas Perkebunan Provinsi Riau). The monthly international CPO prices were gathered from Index Mundi and the monthly domestic CPO prices were from Kharisma Pemasaran Bersama Nusantara Ltd. The data obtained are then processed into natural logarithm form. This is done to overcome time series data that often have large-scale differences over time. Natural logarithm transformation also shows trends (Troutt et al., 1995).

Data Analysis

The stationarity test is conducted to avoid spurious regression in regression tests using time series data. The test is performed using the Augmented Dickey-Fuller (ADF) test. The equation model for the stationarity test in this study is:

$\Delta\ln(FFBF_t) = \alpha_0 + \gamma\ln(FFBF_{t-1}) + \sum_{i=1}^{\rho}\beta_i\Delta\ln(FFBF_{t-i}) + \varepsilon_t$

$\Delta\ln(FFBP_t) = \alpha_0 + \gamma\ln(FFBP_{t-1}) + \sum_{i=1}^{\rho}\beta_i\Delta\ln(FFBP_{t-i}) + \varepsilon_t$

$\Delta\ln(PCPOD_t) = \alpha_0 + \gamma\ln(PCPOD_{t-1}) + \sum_{i=1}^{\rho}\beta_i\Delta\ln(PCPOD_{t-i}) + \varepsilon_t$

$\Delta\ln(PCPOI_t) = \alpha_0 + \gamma\ln(CPOI_{t-1}) + \sum_{i=1}^{\rho}\beta_i\Delta\ln(PCPOI_{t-i}) + \varepsilon_t$

Explanation :

$FFBF_t$	:	average FFB prices at farmer level in period t (IDR/kg)
$FFBF_{t-i}$	:	average FFB prices at farmer level in the previous period (IDR/kg)
$\Delta FFBF_{t-i}$	:	$FFBF_t$ - $FFBF_{t-i}$
$FFBP_t$	:	average FFB prices at the provincial level in period t (IDR/kg)
$FFBP_{t-1}$	:	average FFB prices at the provincial level in the previous period (IDR/kg)
$\Delta FFBP_{t-i}$	:	$FFBP_{t-1}$ - $FFBP_{t-1}$
$PCPOD_t$	:	average domestic CPO prices in period t (IDR/kg)
$PCPOD_{t-1}$	:	average domestic CPO prices in the previous period (IDR/kg)
$\Delta PCPOD_{t-i}$	:	$CPOD_t$ - $CPOD_{t-1}$
$PCPOI_t$	:	average international CPO prices in period t (USD/MT)
$PCPOI_{t-1}$	:	average international CPO prices in the previous period (USD/MT)
$\Delta PCPOI_{t-i}$	:	$CPOI_t$ - $\Delta CPOI_{t-i}$
α_0, γ, β	:	parameter coefficients
ε_t	:	residual of the equation
t	:	time trend

In time series data, determining the ideal lag is very important because economic policy usually takes time to have an impact that can be seen and felt. After all, it does not have a direct impact on economic activity. There are several criteria for determining the optimal lag length, namely, the Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), Hannan Quinn Information Criterion (HQ) or Final Prediction Error (FPE). This research uses AIC values. The smaller the AIC value, the better the model fit (Chang, 2008).

In this research, cointegration testing is used to show the long-term relationship between the variables of FFB prices at the farm level and domestic FFB, domestic FFB prices and domestic CPO, and domestic CPO and international CPO prices. Cointegration is defined as a linear relationship in the long run. If data move together over the long term, it is said to be cointegrated. The cointegration between variables can be determined based on two statistical tests, namely, trace statistics trace (τ) and maximum eigenvalue test (λmax). One of the cointegration testing methods is the Johansen Cointegration test, carried out using a trace test (TS) with the equation:

$$\lambda_{trace}(r) = -T\sum_{i=r+1}^{n}\ln(1-\lambda_i)$$

And Maximum Eigenvalue (ME) with the equation:

$$\lambda_{max}(r, r+1) = -T\ln(1-\lambda_{r+1})$$

Johansen and Juselius (1990) provide critical values for these two tests, where there is a cointegration relationship in the research variables if the TS and ME values are greater than the t-statistic value.

The VAR model reflects time series variables (LeSage, 1990). Each variable in the VAR system of equations is a linear function of its lagged values and those of other variables. The VAR model aims to accurately describe economic phenomena by minimizing theoretical assumptions. The VAR/VECM test can predict whether there is interdependence between the prices of independent smallholder FFB and CPO, both spatially and vertically, in domestic and international markets. In the VAR/VECM model, it is assumed that all dependent variables are stationarity and that all errors are white noise. Non-stationarity variables will result in spurious regression. The specifications for the VAR model connecting the three markets are as follows:

$$\Delta FFBF_t = \alpha_1 + \sum_{i=1}^{\rho}\beta_{11,i}\Delta FFBF_{t-i} + \sum_{i=1}^{\rho}\beta_{12,i}\Delta FFBP_{t-i} + \sum_{i=1}^{\rho}\beta_{13,i}\Delta PCPOD_{t-i} + \sum_{i=1}^{\rho}\beta_{14,i}\Delta PCPOI_{t-i} + \lambda_1 ECT_{t-1} + \varepsilon_{tFFBF}$$

$$\Delta FFBP_t = \alpha_2 + \sum_{i=1}^{\rho}\beta_{21,i}\Delta FFBF_{t-i} + \sum_{i=1}^{\rho}\beta_{22,i}\Delta FFBP_{t-i} + \sum_{i=1}^{\rho}\beta_{23,i}\Delta PCPOD_{t-i} + \sum_{i=1}^{\rho}\beta_{24,i}\Delta PCPOI_{t-i} + \lambda_2 ECT_{t-1} + \varepsilon_{tFFBP}$$

$$\Delta PCPOD_t = \alpha_3 + \sum_{i=1}^{\rho}\beta_{31,i}\Delta FFBF_{t-i} + \sum_{i=1}^{\rho}\beta_{32,i}\Delta FFBP_{t-i} + \sum_{i=1}^{\rho}\beta_{33,i}\Delta PCPOD_{t-i} + \sum_{i=1}^{\rho}\beta_{34,i}\Delta PCPOI_{t-1} + \lambda_3 ECT_{t-1} + \varepsilon_{tPCPOD}$$

$$\Delta PCPOI_t = \alpha_4 + \sum_{i=1}^{\rho}\beta_{41,i}\Delta FFBF_{t-i} + \sum_{i=1}^{\rho}\beta_{42,i}\Delta FFBP_{t-i} + \sum_{i=1}^{\rho}\beta_{43,i}\Delta PCPOD_{t-i} + \sum_{i=1}^{\rho}\beta_{44,i}\Delta PCPOI_{t-i} + \lambda_4 ECT_{t-1} + \varepsilon_{tPCPOI}$$

Explanation :

$FFBF_t$	:	average FFB prices at farmer level in period t (IDR/kg)

$FFBF_{t-i}$: average FFB prices at farmer level in the previous period (IDR/kg)
$FFBP_t$: average FFB prices at the provincial level in period t (IDR/kg)
$FFBP_{t-i}$: average FFB prices at the provincial level in the previous period (IDR/kg)
$PCPOD_t$: average domestic CPO prices in period t (IDR/kg)
$PCPOD_{t-i}$: average domestic CPO prices in the previous period (IDR/kg)
$PCPOI_t$: average international CPO prices in period t (USD/MT)
$PCPOI_{t-i}$: average international CPO prices in the previous period (USD/MT)
$\alpha_1, \alpha_2, \alpha_3, \alpha_4$: Intercept
Δ : long-term dynamic parameter
$\lambda_i ECT_{t-i}$: error correction term from previous period
ε_t : error term of the equation
t : Time trend

The VECM equation for international CPO market integration with independent smallholder FFB prices in vector form is

$$\Delta Y_t = \begin{bmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ \alpha_4\end{bmatrix} + \begin{bmatrix}\mu_{lnFFBF}\\ \mu_{lnFFBP}\\ \mu_{lnPCPOD}\\ \mu_{lnPCPOI}\end{bmatrix} + \omega_{t-1}\beta + \begin{bmatrix}\delta_{11} & \delta_{21} & \delta_{31} & \delta_{41}\\ \delta_{12} & \delta_{22} & \delta_{32} & \delta_{42}\\ \delta_{13} & \delta_{23} & \delta_{33} & \delta_{43}\\ \delta_{14} & \delta_{24} & \delta_{34} & \delta_{44}\end{bmatrix} \begin{bmatrix}\Delta lnFFBF_{t-1}\\ \Delta lnFFBP_{t-1}\\ \Delta lnPCPOD_{t-1}\\ \Delta lnPCPOI_{t-1}\end{bmatrix} + \begin{bmatrix}\varepsilon_{lnFFBF}\\ \varepsilon_{lnFFBP}\\ \varepsilon_{lnPCPOD}\\ \varepsilon_{lnPCPOI}\end{bmatrix}$$

Explanation :
ΔY_t : $\Delta FFBF_t$; $\Delta FFBP_t$; $\Delta CPOD_t$; $\Delta CPOI_t$
$FFBF_t$: average FFB price at farmer level in period t (IDR/kg)
$FFBF_{t-1}$: average FFB price at farmer level in the previous period (IDR/kg)
$\Delta FFBF_{t-1}$: $FFBF_t$ - $FFBF_{t-i}$
$FFBP_t$: average FFB price at the provincial level in period t (IDR/kg)
$FFBP_{t-1}$: average FFB price at the provincial level in the previous period (IDR/kg)
$\Delta FFBP_{t-1}$: $FFBP_t$ - $FFBP_{t-i}$
$PCPOD_t$: average domestic CPO price in period t (IDR/kg)
$PCPOD_{t-1}$: average domestic CPO price in the previous period (IDR/kg)
$\Delta CPOD_{t-1}$: $PCPOD_t$ - $PCPOD_{t-1}$
$PCPOI_t$: average international CPO price in period t (USD/MT)
$PCPOI_{t-1}$: average international CPO price in the previous period (USD/MT)
$\Delta PCPOI_{t-1}$: $PCPOI_t$ - $PCPOI_{t-1}$
$\alpha_1, \alpha_2, \alpha_3, \alpha_4$: intercept
Δ : long-term dynamic parameter
ε_t : residual of the equation
t : time trend

Time series data tend to be non-stationarity so that such can produce a spurious regression model. This is a condition where the results of statistical processing show a high R^2 and have a significant t statistic, but the results obtained are not scientifically meaningful. The unit root test can be used to test the stationarity of each variable. In price transmission analysis, causality testing ensures the direction of the causal relationship between variables. Price transmission analysis in this study uses a causality test to determine whether the source of FFB price transmission is from farmers, domestically or internationally. The standard causality model further developed by Engle and Granger (1987) stated that if there is a long-term relationship (cointegration) between two or more non-stationarity variables, then the short-term dynamics between these variables can be explained through an error correction model.

Results and Discussion

The unit root test is a statistical test used to determine whether a time series is stationarity. Non-stationarity time series can have inconsistent trends or patterns, which makes predictions more difficult and models built on these data can be unstable. ADF (Augmented Dickey-Fuller) is a standard method to test unit roots. ADF is extended over basic Dickey-Fuller test by adding additional lags of the variables under test to capture more complex dynamics of time series data.

Table 1 Results of data stationarity test with the ADF test

Variabe	Level I(0)	Explanation	1st difference (1)	Explanation
ln(FFBF)	0.3377	non-stationarity	0.0000	stationarity
ln(FFBP)	0.2262	non-stationarity	0.0000	stationarity
ln(CPOD)	0.3988	non-stationarity	0.0001	stationarity
ln(CPOI)	0.5990	non-stationarity	0.0000	stationarity

Stationarity testing was performed using the Augmented Dickey–Fuller (ADF) test to determine whether the time series data are stationary (Table 1). Based on the test results at the (I(0)) level, all variables namely, ln(FFBF), ln(FFBP), ln(CPOD), and ln(CPOI), have probability values greater than 0.05, thus being declared non-stationary at the level. Furthermore, testing was performed at the first difference (I(1)) level and showed that all variables have probability values less than 0.05, thus being stationary at the first difference level. Thus, it can be concluded that all variables are integrated at the

first order (I(1)) and meet the requirements for further analysis using the cointegration approach or VECM.

Determining the optimal lag length is the next step after testing data stationarity. Determining the lag length in VAR model estimation is important to eliminate autocorrelation and heteroscedasticity problems. Determining the length of the lag can be done using the available information criteria, namely, the Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), and Hannan-Quinn Criterion (HQ). Table 2 showed the results of the lag length test, indicating that the optimal lag length selected is 1 based on the Schwarz Criterion (SC). The lag length chosen was lag 2 according to the SC results.

The Johansen Cointegration Test, the cointegration test, was used to determine the relationship between the FFB market at the independent farmer level in Riau Province, province, and domestic CPO prices and international CPO prices. Decision-making rules are carried out by looking at the Trace statistics or Max-Eigen statistics values. Suppose the trace statistics or max-Eigen statistics value exceeds the critical value. In that case, cointegration has occurred in the system of equations being analyzed. Table 3 showed the results of the FFB market cointegration test at the independent farmer level in Riau Province and domestic and CPO at the domestic and international levels.

If the trace statistic and Max-Eigen statistic values were greater than the critical value, the equation has a long-term relationship or cointegration. There are four cointegrated equations between the variables in the model, or it can be said that the FFB market at the farmer and provincial levels and CPO at the domestic and international levels are integrated in the long term. The research results consistently show significant cointegration between the third variable, farmer's FFB prices, provincial level prices, domestic CPO prices, and international CPO prices. Up to three vector cointegrations indicate a strong long-run equilibrium relationship between these variables. These findings imply that despite short-term fluctuations, the third set moves together in the long run, maintaining a stable relationship. This can be important for economic modelling, forecasting and policy analysis regarding these markets.

Cointegration of The FFB Price

Table 4 shows the results of VECM. These results show cointegration test of the long-term relationship between farmers' prices for FFB and FFB prices at the provincial level, as domestic and international CPO prices. The results in Table 4 show that in the long term, FFB prices at the farm level are significantly and positively influenced by domestic CPO prices (α=1%) and international CPO prices (α=1%). The CPOD(-1) coefficient is significant at the 1 percent level with a negative coefficient value (-2.63792). This indicates that changes in

Table 2 Determining the optimal lag length of FFB and CPO international prices

Lag	LogL	LR	FPE	AIC	SC	HQ
1	478.8550	NA	9.29e-10	-9.446019	-9.023984*	-9.275315
2	504.8087	**47.67006***	**7.59e-10***	**-9.649156***	-8.805085	**-9.307747***
3	517.7228	22.66558	8.11e-10	-9.586179	-8.320072	-9.074065
4	529.4069	19.55296	8.92e-10	-9.498099	-7.809957	-8.815280
5	539.9589	16.79711	1.01e-09	-9.386916	-7.276738	-8.533393
6	546.8007	10.33260	1.24e-09	-9.200015	-6.667802	-8.175787
7	554.2023	10.57360	1.51e-09	-9.024536	-6.070287	-7.829603
8	560.4095	8.360735	1.91e-09	-8.824683	-5.448399	-7.459046
9	579.5871	24.26560	1.87e-09	-8.889533	-5.091214	-7.353191
10	591.9496	14.63319	2.13e-09	-8.815299	-4.594944	-7.108252

Note: Exp: *significant at the 10 percent level; **significant at the 5 percent level; ***significant at the 1 percent level

Table 3 Cointegration test result

Hypothesized number of cointegration	Lag	Trace test		Max Eigen-value test	
		Trace Statistic	0.05 Critical Value	Max Eigen statistic	0.05 Critical Value
None	1	65.77289*	47.85613	29.63391*	27.58434
At most 1	1	36.13898*	29.79707	20.57097	21.13162
At most 2	1	15.56801*	15.49471	12.55487	14.26460
At most 3	1	3.013135	3.841466	3.013135	3.841466

Note: Exp: *significant at the 10 percent level; **significant at the 5 percent level; ***significant at the 1 percent level

Table 4 Long-term cointegration of the FFB smallholder price, FFB at the provincial level, domestic and international CPO

Cointegrating Eq.	CointEq1
FFBF(-1)	1.000000
FFBP(-1)	-0.057972 (0.09026) [0.64228]
CPOD(-1)	0.583393 (0.22116) [-2.63792]***
CPOI(-1)	0.389399 (0.16313) [-2.38699]**
C	0.003430

Note: T table: t(α=1%) = 2.623465496, t(α=5%)= 1.982815274, t(α=10%) = 1.659495383
Exp: *significant at the 10 percent level; **significant at the 5 percent level; ***significant at the 1 percent level

domestic CPO prices in the long term significantly affect farmers' FFB prices, but the direction of the effect is negative. The CPOI(-1) coefficient is significant at the 5 percent level with a negative value (-2.38699), which means that international CPO prices also significantly negatively affect farmers' FFB prices in the long term. The negative effects of domestic and international CPO prices on farmers' FFB prices may indicate an imbalance in the distribution of benefits along the value chain. Farmers may not fully benefit from increasing CPO prices, which may indicate price asymmetry

Rifin stated that Indonesian domestic CPO prices do not cointegrate with international CPO prices, meaning that prices do not influence prices in the domestic market in the international market (Rifin, 2009). Alamsyah et al. (2021) stated that the prices received by independent smallholder farmers were lower than those from plasma farmers. The results in Table 4 show that domestic and international CPO prices significantly and positively influence FFB prices in Riau Province in the long term.

Higher CPO prices on the global market will raise domestic CPO prices, increasing the prices received by FFB farmers. Conversely, lower CPO prices tend to reduce FFB prices. In the long term, this influence will continue, with CPO price fluctuations in global markets playing a key role in determining local FFB prices. Nesti et al. (2018) reported that the role of CPO exporters greatly influences the price of FFB. The power of influence of exporters can influence the selling price of FFB. While Dahniar and Difa (2021) stated that FFB price depends on quality and process during harvesting.

A timely and efficient harvesting process is essential to ensure that the FFB is at peak maturity when harvested, which is optimal for oil production. Good harvest practices, such as choosing the right harvest time and careful handling to avoid damage, also improve the quality of FFB and ultimately influence the prices farmers can receive. Smallholder farmers have a low bargaining position (Darmawan, 2019; Nesti et al., 2018). This leaves farmers as price takers only.

Table 5 shows the short-term cointegration relationship between smallholder farmers' and provincial FFB markets and CPO markets at both domestic and international levels. The Error Correction Term (CointEq) had a significant negative coefficient value (-0.405307) in the D(LNFFFB) model (farmer's FFB price), indicating that there is an adjustment mechanism towards long-term equilibrium. D(FFBP(-1)) is not significant to DFFFB, but DFFBP(-2) is significant at the 10 percent level with a positive value (0.177899). This shows that changes in FFB prices at the provincial level affect farmer prices with a delay. The coefficient value of DCPOD(-1) has a positive but insignificant effect, while DCPOI(-1) is significantly positive to DFFFB at the 1 percent level with a coefficient (0.482998). This shows that international CPO prices affect farmer FFB prices more quickly in the short term than domestic CPO prices. The response of farmer FFB prices to price changes at the provincial and international levels has a different pattern in the short term. The presence of a delay in response to provincial prices (lag 2) and a significantly faster influence than international prices indicate asymmetry in the price transmission mechanism.

Price is an indicator of farming and marketing efficiency for a commodity. The dependence of the Indonesian palm oil industry on the export market means that international CPO prices greatly influence domestic CPO and FFB prices. Riau is the largest FFB producing province in Indonesia and has the largest number of independent farmers. Plantation Service in Riau Province sets prices periodically to avoid unfair competition for farmers. However, in the field, many actors, namely, collectors and palm oil companies, play an unofficial role in determining prices.

Causality testing aims to ascertain the direction of price transmission. Can the direction of price transmission come from the supply/upstream side (producers) or from the demand/downstream side (consumers). This test is carried out to see the direction of price transmission, namely, price shocks caused by changes in demand (price transmission from downstream to upstream) or shocks due to changes in supply (price transmission from upstream to downstream). Table 6 shows the results of the Granger causality test between independent smallholder FFB prices, domestic CPO prices, and international CPO prices.

Table 5 Short Term Cointegration of smallholder farmers' and provincial FFB and CPO markets at domestic and international levels

Error Correction:	D(LNFFBF)	D(LNFFBP)	D(LNCPOD)	D(LNCPOI)
CointEq	-0.405307 (0.12310) [-3.29250]***	-0.025319 (0.17291) [-0.14643]	-0.064560 (0.11373) [-0.56765]	0.172227 (0.08927) [1.92935]*
DFFBF(-1)	0.132559 (0.15300) [0.86640]	0.357168 (0.21491) [1.66196]*	0.263957 (0.14136) [1.86731]*	-0.126867 (0.11095) [-1.14348]
DFFBF(-2)	0.024038 (0.10422) [0.23064]	0.200914 (0.14640) [1.37240]	0.088367 (0.09629) [0.91769]	-0.065430 (0.07558) [-0.86572]
DFFBP(-1)	-0.039100 (0.09770) [-0.40019]	-0.215925 (0.13724) [-1.57334]	0.007602 (0.09027) [0.08421]	-0.079837 (0.07085) [-1.12683]
DFFBP(-2)	0.177899 (0.09739) [1.82669]*	-0.151154 (0.13680) [-1.10496]	0.104138 (0.08998) [1.15738]	-0.009950 (0.07062) [-0.14088]
DCPOD(-1)	0.313395 (0.20635) [1.51874]	0.215638 (0.28985) [0.74397]	-0.198743 (0.19065) [-1.04245]	0.482998 (0.14964) [3.22779]***
DCPOD(-2)	-0.081610 (0.20418) [-0.39971]	-0.320244 (0.28679) [-1.11664]	-0.299823 (0.18864) [-1.58941]	0.060512 (0.14806) [0.40870]
DCPOI(-1)	-0.129782 (0.16775) [-0.77366]	0.031567 (0.23563) [0.13397]	0.017448 (0.15498) [0.11258]	0.079407 (0.12165) [0.65278]
DCPOI(-2)	-0.098553 (0.15177) [-0.64935]	0.005330 (0.21318) [0.02500]	-0.015292 (0.14022) [-0.10905]	0.041113 (0.11006) [0.37356]
c	0.004679 (0.00931) [0.50262]	0.005125 (0.01308) [0.39196]	0.002241 (0.00860) [0.26053]	0.001655 (0.00675) [0.24512]

Note: T table: t(α=1%) = 2.623465496, t(α=5%)= 1.982815274, t(α=10%) = 1.659495383
Exp: *significant at the 10 percent level; **significant at the 5 percent level; ***significant at the 1 percent level

Table 6 The causality test of independent smallholder FFB prices, domestic CPO prices, and international CPO prices

Causality	Lag	F-Statistic	Prob.
FFBP → FFBF	1	8.58618***	0.0042
FFBF → FFBP	1	2.17109	0.1436
CPOD → FFBF	1	33.1774***	9.E-08
FFBF → CPOD	1	0.85782	0.3565
CPOI → FFBF	1	13.4744***	0.0004
FFBF → CPOI	1	7.78830***	0.0063
CPOD → FFBP	1	0.46616	0.4963
FFBP → CPOD	1	1.12316	0.2917
CPOI → FFBP	1	0.98749	0.3227
FFBP → CPOI	1	3.61809*	0.0599
CPOI → CPOD	1	1.30977	0.2551
CPOD → CPOI	1	11.5908***	0.0009

*significant at the 10 percent level, **significant at the 5 percent level, ***significant at the 1 percent level

The price of FFB at the province level significantly affects the price of FFB at the farmer level (significant at the 1% level). However, the price of FFB at the farmer level does not affect the price of FFB at the provincial level. The relationship between domestic CPO prices and FFB at the farmer level has a significant effect (15) but not vice versa. The international CPO price has a significant effect (1%) on the price of FFB at the smallholder farmer level. The price of FFB at the farmer level also shows a significant relationship (1%) to the international CPO price. The relationship between domestic CPO prices and FFB at the provincial level and vice versa does not have a significant effect. The relationship between international CPO prices and FFB at the provincial level shows insignificant results, but the provincial FFB price shows a significant relationship at the 10 percent level.

The international CPO price does not show a significant relationship with the domestic CPO price but the domestic CPO price shows a significant relationship (1%) to the international CPO price. Although there is price transmission from international to domestic and farmer markets, some relationships such as from provincial prices (FFBP) to domestic or international markets are less significant. Domestic CPO prices significantly affect FFB prices at the smallholder level. This indicates price transmission from the domestic CPO market to the farmer level. The insignificant relationship between FFBF and CPOD indicates that FFB prices at the farmer and provincial levels do not directly affect domestic CPO prices.

Farmers may not get a fair price for their FFB, hindering motivation to increase production and investment in the sector. Reliance on international markets for pricing also increases vulnerability to international price and policy fluctuations. Therefore, efforts are needed to increase market efficiency, strengthen pricing policies, and diversify the market to support the long-term welfare of oil palm farmers.

Farmers may not benefit from rising CPO prices in international or domestic markets. For example, if CPO prices rise but FFB prices do not rise by the same proportion, farmer incomes remain low despite the potential for higher profits. This uncertainty in pricing can cause farmers difficulties in financial and investment planning. Domestic price instability that does not fully reflect international prices can cause uncertainty among CPO farmers and processors. This can also affect long-term investment in the palm oil sector, because market players may view this sector as less stable or too risky.

For the lag length test results (Table 2), the lag length used is 2 by AIC recommendations. The lag length of 2 chosen by AIC reflects the selection of the most efficient model, where one previous period is sufficient to capture the information needed to predict the target variable. Then, the cointegration test was to continue to determine the long-term relationship between independent smallholder FFB prices and FFB prices in Riau province, domestic CPO prices, and CPO prices on the international market. The cointegration test showed that the price of FFB for independent farmers in Riau Province has a long-term relationship with FFB prices in the province, domestic and international CPO prices.

Price disparity is common in many markets (Lach & Moraga-González, 2017). Riau Province, one of Indonesia's most enormous palm oil-producing regions, plays a central role in the dynamics of FFB prices. Riau is one of Indonesia's largest palm oil production centers, so the FFB price in this province is often considered a reference for FFB prices throughout the region. FFB prices at the provincial level are usually determined by committees or associations that consider various factors including CPO prices, production costs, and demand and supply in local and international markets. Transportation costs from the plantation location to the processing factory will also affect the price received by farmers.

In Indonesia, local governments often set FFB reference prices for various quality levels and locations. This price is determined periodically and is used as a guide by farmers and processing plants. Price policies set in Riau Province reflect local market conditions and are influenced by regional government policies, which seek to balance the interests of farmers and processing factories. The amount of FFB available from farmers also influences prices. If there is excess supply, prices can fall, affecting farmers' income. The price of FFB in Riau Province directly affects the income of oil palm farmers. When FFB prices at the provincial level rise, farmers get higher prices for their FFB, which increases their income. The prices received by oil palm farmers have a direct impact on their economic welfare. Higher FFB prices allow farmers to reinvest in their gardens, improve quality of life, and support local communities.

Biodiesel production in Indonesia will reportedly increase the biodiesel industry's demand for FFB (Rianawati et al., 2021; Simangunsong et al., 2019). Increased demand for FFB from the biodiesel industry can push FFB prices up. When processing plants and biodiesel producers need more CPO as raw material, they will offer better prices to farmers to ensure sufficient FFB supplies. With consistent demand from the biodiesel sector, FFB prices can become more stable. This reduces dependence on price fluctuations in the international CPO market, providing income stability for farmers.

Conclusion and Recommendation

This study reveals significant price asymmetry in the transmission of FFB prices at the farmer level. In the long term, fluctuations in domestic and international CPO prices have a negative impact on farmer prices, indicating that farmers do not fully benefit from rising CPO prices. In the short term, farmer prices respond more slowly to domestic (provincial) price movements than to international prices, suggesting an imbalance in domestic price transmission. These inefficiencies may be driven by market power disparities between palm oil mills and smallholder farmers, as well as regional pricing dynamics that hinder fair price adjustments, pointing to potential market failures. To address this, local governments should strengthen the FFB pricing mechanism to better reflect market dynamics, including stricter supervision of palm oil mills' adherence to provincial reference prices. At the same time, farmers are encouraged to establish strong cooperatives to enhance their bargaining position and negotiate fairer selling prices.

The actions recommended to correct market distortion are provincial and district governments should enhance monitoring to ensure palm oil mills comply with provincial reference prices. Regular price adjustments should be made better to align FFB prices with fluctuations in international CPO prices. This will help ensure fairer price transmission to farmers. Oil palm farmer groups should be formed and strengthened to improve farmers' bargaining power. These cooperatives can help negotiate better prices and reduce reliance on middlemen. Collective action will allow farmers to access better market opportunities.

Conflict of Interest

The authors declare that there are no conflicts of interest associated with the publication of this article. In this case, the author declares that there are no relationships or conditions that negatively influence objectivity, honesty or fairness in the preparation and publication of this article.

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