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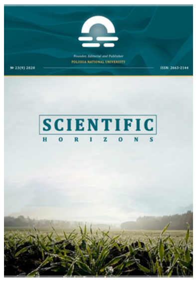

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Cross-commodity market integration and price transmission in Thailand's livestock sector

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Abstract. The ability to substitute goods and services is crucial for maintaining market stability during price fluctuations, particularly in the livestock market, where products are interchangeable. This study aimed to analyse market integration and asymmetric price transmission concerning livestock commodity prices in Thailand. Specifically, it focused on beef cattle, swine, broiler chicken, and chicken egg prices, using time-series data from January 2011 to December 2022. The analysis employed unit root tests to check if the time series data were stationary, Granger causality tests to determine the direction of relationships among livestock prices and an asymmetric price transmission model to examine short-term asymmetry and adjustment in cross-commodity prices. The findings indicate three directions of price integration in Thailand's livestock market: from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price. The results suggest that price transmission in Thailand is symmetrical, demonstrating an efficient interdependent relationship. Thus, the findings indicate that chicken eggs are a substitute for broiler chickens and swine when prices fluctuate, while broiler chickens are a substitute for swine. The results reveal that chicken eggs can replace swine consumption more effectively than broiler chickens within Thailand. This study highlights that chicken eggs are the most effective substitute during livestock price fluctuations in Thailand, with broiler chickens being the second most effective. Consequently, stakeholders in the livestock supply chain, such as policymakers, entrepreneurs, and farmers, should understand the integration of different commodities and price transmission in Thailand's livestock market. To guarantee market stability, stakeholders should manage the demand and supply of livestock commodities and acquire chicken eggs and broiler chickens during significant fluctuations in domestic livestock commodity prices

Keywords: market power; price stability; price adjustment; commodity; substitute; asymmetry

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INTRODUCTION

The livestock sector has played an important role in Thailand's agricultural development. It has advanced with modern production technology, meeting high international standards. Moreover, livestock production is a crucial source of income for agricultural households at both the farm and industrial levels. It generates substantial revenue for the agricultural sector and contributes significantly to export earnings from livestock products, which can amount to hundreds of billions of baht per year. The main types of livestock, including beef cattle, dairy cows, swine, broilers, and laying hens, have been developed through modern production management systems, hygienic and standardised animal housing, and government support for research and development in livestock production. As a result, farmers have demonstrated increased interest in raising animals and producing high-quality livestock products for domestic and international markets. That has led to increased investment in livestock businesses to meet consumer demands.

According to the 2022 report by the Office of Agricultural Economics (2023), the main livestock products exported by Thailand comprised chicken meat and products (141,962 million baht), dairy products (14,759 million baht), live beef cattle and products (3,428 million baht), pork products (1,351 million baht), and chicken eggs (1,162 million baht). The average exchange rate between the Thai baht and the US dollar was 35.0653 baht per US dollar in 2022. The report emphasises that demand for livestock products has been growing domestically and internationally, with countries such as Japan, the EU, and ASEAN member states being significant markets for Thai livestock products.

The livestock production sector in Thailand is positioned for expansion, driven by increasing domestic and international demand. However, the country's animal feed production relies heavily on imported raw materials, making the cost of domestic feed vulnerable to fluctuations in feedstuff raw material prices. Changing global supply and demand also contribute to substantial fluctuations in animal feed prices. External factors, such as climate change and conflicts in major producing countries of feedstuff raw materials like Russia and Ukraine, could also influence global feed costs. Animal feed constitutes an average of 60-70 per cent of the overall cost of livestock production in the country, making its cost a significant contributor to the prices of livestock products (Vorapojwisit, 2023). Thailand has been affected by African Swine Fever (ASF), which has severely impacted the economy and swine farming industry. The impact of the swine disease has caused the price of pork to increase dramatically, resulting in consumers opting for other products such as chicken, eggs, and beef. Therefore, it can be concluded that the prices of livestock products in Thailand are subject to high volatility, which can be attributed to several factors, including rising production costs, dependence on raw materials for animal feed from foreign sources, and the outbreak of animal diseases that can disrupt production. Despite these challenges, consumers can opt for alternative livestock commodities as substitute goods that may be more readily available, mitigating the impact of price volatility on their consumption habits.

This study aimed to analyse market integration and asymmetric price transmission in Thailand's livestock products (cross-commodity), focusing on beef cattle, swine, broiler chickens, and chicken eggs.

LITERATURE REVIEW

Several studies have analysed the price transmission of agricultural commodities, both vertically and horizontally, as well as the price integration among them that determines the market price. Vertical price integration occurs when price impacts are transmitted within the same commodity at different price levels, such as farm-gate, wholesale, retail, and export prices. In contrast, horizontal price integration occurs at the same price level but with varying transmission across different market regions, such as northern, central, and southern market prices. For instance, L. Deb *et al.* (2020) analysed market integration and price transmission in the vertical rice markets of Bangladesh using monthly time series data from November 2006 to June 2017. This study applied various econometric methodologies, including ADF and PP unit root tests for stationarity, Granger causality tests for identifying price transmission, and threshold autoregressive (TAR) and momentum threshold autoregressive (M-TAR) models for detecting asymmetric impacts among rice market prices in Bangladesh. The results indicated that a long-run equilibrium exists among farm-gate, wholesale, and retail rice prices. Asymmetric testing revealed both the short-run and long-run asymmetries in price transmission within vertical supply chains, affecting both the producers and consumers due to positive and negative asymmetries.

Shortly thereafter, T. Rudinskaya and I. Boskova (2021) investigated asymmetric price transmission in the dairy supply chain in the Czech Republic using the vector error correction model (VECM). Firstly, the study revealed that an increase in farm-gate prices had a greater impact on processor prices for drinking milk than a decrease in the same price level. Moreover, an increase in processor prices had a smaller effect on retail prices than a decrease in the same price level. Secondly, for butter, an increase in processor prices led to a greater impact on retail prices than a decrease in the unit price. Finally, for cheese, an increase in processor prices had a stronger effect on retail prices than a decrease in the unit price. The findings of T. Rudinskaya and I. Boskova (2021) provide a better understanding of the dynamics of price transmission in the dairy supply chain and have significant implications for producers, processors, and retailers in the industry. Furthermore, M.C. Rahman *et al.* (2022) analysed rice price transmission in Bangladesh using time series methods from October 2005 to June 2017. The study found that the rice market in Bangladesh exhibits a long-run asymmetric relationship among the farm-gate, wholesale, and retail prices. The findings of V. Onegina *et al.* (2022) also support the concept of vertical price transmission in the agricultural market, especially in the case of the milk market in Ukraine, which is asymmetrical. Specifically, when the price of raw milk increases, the prices of processors and retailers rise by a larger magnitude. Additionally, when a shock occurs in the price of raw milk, it immediately impacts the prices of processors and retailers.

The impact of price changes can be transmitted to different types of commodities that serve as substitutes, particularly evident in agricultural markets. For example, O.H. Onubogu and A.O. Dipeolu (2021) studied the price transmission between cowpea and yam markets in Nigeria using Johansen cointegration, Granger causality, and VECM. Their findings confirmed the market integration between cowpea and yam prices. Similarly, the findings of S. Saghaian *et al.* (2018) indicated that price volatility can be transmitted asymmetrically about the prices of biofuels and maize in the United States. Furthermore, M. Zungo and F.T.M. Kilima (2019) estimated the price integration between maize and rice markets in Tanzania by employing cointegration and ECM analysis. Their study found strong evidence of market integration between the two price series. In addition, the study by P. Ramoroka and C.L. Muchopa (2022) analysed the cross-commodity price transmission between maize and wheat in South Africa using the Granger causality approach. The results revealed that changes in maize prices significantly affected wheat prices. Furthermore, M.A. Monteiro and B.D. Jammer (2024) supported the inter-commodity relationship in the case of grain and livestock prices in South Africa by employing time series analysis.

MATERIALS AND METHODS

This study employed secondary data in the form of monthly time series spanning the period from January 2011 to December 2022, totalling 144 months. The data were obtained from the Office of Agricultural Economics (2023) of Thailand. Notably, the analysis excludes livestock price data from 2023, as the government commenced intervening in the market during that time to stabilise swine prices, which had become volatile due to disease outbreaks. These interventions involved short-term adjustments to better align supply and demand with domestic needs. Additionally, around this time, Thailand detected smuggled pork imports, which could have distorted livestock prices, inducing them to deviate from true market conditions and potentially causing price distortions. The study analysed the market integration and price transmission in the major livestock commodities in Thailand using farm-gate price levels consisting of four variables: (1) the price of medium-sized live beef cattle (unit: baht per head) representing the price of beef cattle (P_C), (2) the price of live swine weighing 100 kilograms or more (unit: baht per kilogram) representing the price of swine (P_S), (3) the price of broiler chickens (unit: baht per kilogram) representing the price of broiler chickens (P_B), and (4) the price of assorted chicken eggs (unit: baht per hundred bubbles) representing the price of chicken eggs (P_E). To describe the relationship between the variables as a percentage change, known as elasticity, the variables were adjusted using the natural logarithmic function (ln). The time series plot of the variables, including P_C, P_S, P_B, and P_E, is presented in Figure 1.

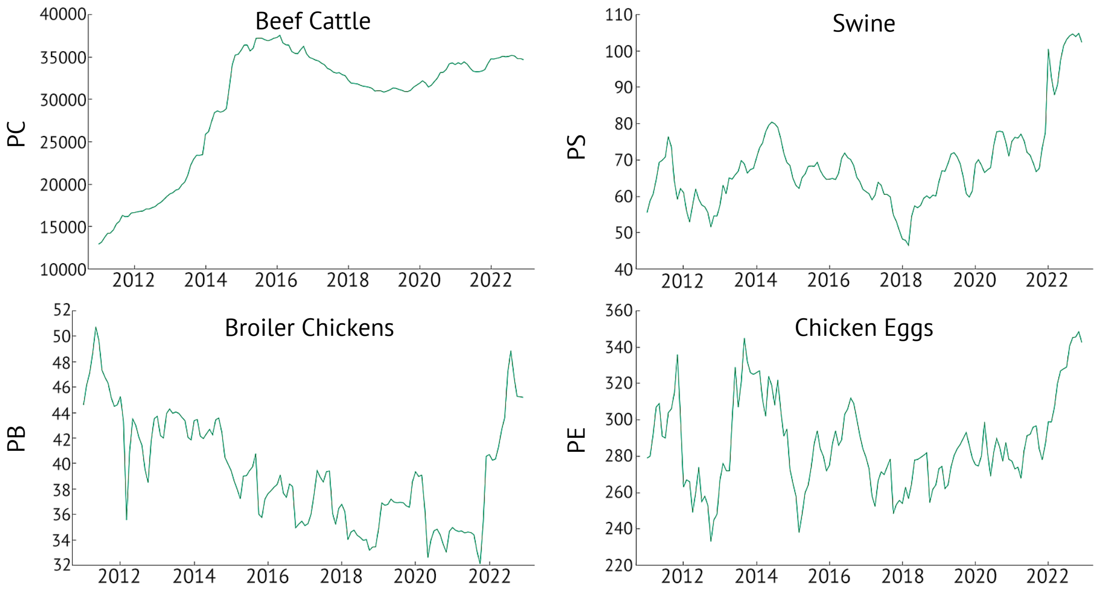

Figure 1. *Monthly beef cattle (P_C), swine (P_S), broiler chicken (P_B), and chicken egg (P_E) prices*
Source: *compiled by the author based on data from the Office of Agricultural Economics (2023), Thailand*

Figure 1 illustrates a time series of farm-gate price levels for four different livestock commodities: beef cattle, swine, broiler chickens, and chicken eggs. In 2022, there was a significant upward trend in the prices of three variables: P_S, P_B, and P_E, while P_C showed only a slight increase. The descriptive statistics and correlation matrix of the variables, including beef cattle price (P_C), swine price (P_S), broiler chicken price (P_B), and chicken egg price (P_E), are presented in Tables 1 and 2, respectively.

***Table 1**. Descriptive statistics of the variables*

Variable	Mean	Maximum	Minimum	S.D.	Skewness	Kurtosis
P_C	29,490.653	37,560.000	12,935.000	7,251.252	-1.001	2.511
P_S	68.425	104.835	46.546	11.839	1.357	5.231
P_B	39.373	50.740	32.100	4.279	0.420	2.289
P_E	286.613	348.540	233.000	24.893	0.520	2.796

***Source:** author's calculation*

Table 1 presents the mean, maximum, minimum, standard deviation (S.D.), skewness, and kurtosis of each variable. Table 2 displays the correlation coefficients between the four variables. The coefficient values in Table 2 indicate the strength and direction of the relationship between each pair of variables. The results suggest a positive correlation between P_S and P_E (0.685), and a weaker positive correlation between P_B and P_E (0.493), between P_S and P_B (0.317), and between P_C and P_S (0.316). Conversely, there is a negative correlation between P_C and P_B (-0.594), and a weak negative correlation between P_C and P_E (-0.002).

***Table 2**. Correlation matrix*

Variable	P_C	P_S	P_B	P_E
P_C	1.000	0.316	-0.594	-0.002
P_S	0.316	1.000	0.317	0.685
P_B	-0.594	0.317	1.000	0.493
P_E	-0.002	0.685	0.493	1.000

***Source:** author's calculation*

Before conducting a causal relationship analysis to detect market integration, it is essential to verify the stationarity of the time series variables to avoid spurious results (Granger & Newbold, 1974). In this study, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests (Dickey & Fuller, 1979; Phillips & Perron, 1988) were utilised to assess the data properties. Both methods are based on one-sided p-values from J.G. MacKinnon (1996). If the level data of the variables are non-stationary, then first differencing is required until the variables exhibit stationarity. After identifying the stationarity of the variables, Granger causality is employed to test the relationships among the variables using a vector autoregressive (VAR) model (Granger, 1969). The multivariate VAR model, which incorporates the variables of P_C, P_S, P_B, and P_E, is presented as Eq. (1)-Eq. (4) below.

$$\Delta P_{C,t} = \alpha_1 + \sum_{i=1}^{p} \beta_{1i}\Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{1i}\Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{1i}\Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{1i}\Delta P_{E,t-i} + \varepsilon_{1t}, \quad (1)$$

$$\Delta P_{S,t} = \alpha_2 + \sum_{i=1}^{p} \beta_{2i}\Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{2i}\Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{2i}\Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{2i}\Delta P_{E,t-i} + \varepsilon_{2t}, \quad (2)$$

$$\Delta P_{B,t} = \alpha_3 + \sum_{i=1}^{p} \beta_{3i}\Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{3i}\Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{3i}\Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{3i}\Delta P_{E,t-i} + \varepsilon_{3t}, \quad (3)$$

$$\Delta P_{E,t} = \alpha_4 + \sum_{i=1}^{p} \beta_{4i}\Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{4i}\Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{4i}\Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{4i}\Delta P_{E,t-i} + \varepsilon_{4t}, \quad (4)$$

where Δ is the differencing order, t represents time, α is the constant, β denotes estimated coefficients, and ε is the error term. The optimal lag order for the VAR(p) model is determined using the lowest values of the Akaike information criterion (AIC). To identify the causal relationship, short-run causality using the standard

F-statistic and long-run block exogeneity using the Wald (χ^2) test are employed to test the null hypothesis (H_0), defined as follows. The null hypothesis of Eq. (1) can be expressed as $\sum_{i=1}^{p}\theta_{1i} = \sum_{i=1}^{p}\phi_{1i} = \sum_{i=1}^{p}\omega_{1i} = 0$. Similarly, the null hypothesis of Eq. (2) is $\sum_{i=1}^{p}\beta_{2i} = \sum_{i=1}^{p}\phi_{2i} = \sum_{i=1}^{p}\omega_{2i} = 0$, while the null hypothesis of Eq. (3) is $\sum_{i=1}^{p}\beta_{3i} = \sum_{i=1}^{p}\theta_{3i} = \sum_{i=1}^{p}\omega_{3i} = 0$. Finally, the null hypothesis of Eq. (4) is $\sum_{i=1}^{p}\beta_{4i} = \sum_{i=1}^{p}\theta_{4i} = \sum_{i=1}^{p}\phi_{4i} = 0$.

After identifying the causal relationship, the outputs were used to analyse price transmission between variables by employing R.F. Engle and C.W.J. Granger's (1987) cointegration and error correction model (ECM) approaches. The cointegration and error correction methods involve three steps. Firstly, the long-run equilibrium was determined by testing for possible cointegration and estimating the residual series from the estimation of Eq. (5). Secondly, the residual series was tested for stationarity, which could lead to two outcomes. If the residual series was stationary at the level stage with a contained unit root I(0) process, it would imply that the variables in the first step are cointegrated with a long-run equilibrium. However, if the residual series could not be stationary at the I(0) process, the estimation in the first step would have spurious results. Finally, if the analysis confirms that the variables are cointegrated with a long-run relationship, it is possible to test short-run adjustments returning to equilibrium using the error correction model (Asteriou & Hall, 2011). The processes of the cointegration and error correction model are described below.

In the first step, the existence of cointegration between Y and X is tested by using the linear combination shown in Eq. (5). The residual series ($\hat{\varepsilon}_t$) is obtained from Eq. (5) as presented in Eq. (6).

$$Y_t = \alpha_0 + \beta_1 X_t + \varepsilon_t, \quad (5)$$

$$\hat{\varepsilon}_t = Y_t - \hat{\alpha}_0 - \hat{\beta}_1 X_t, \quad (6)$$

where Y and X are the time series variables, $\hat{\varepsilon}_t$ is the estimated residual series, and $\hat{\alpha}_0$ and $\hat{\beta}_1$ are the estimated coefficients. If $\hat{\varepsilon}_t$~I(0), it indicates that the relationship between Y and X is cointegrated without any spurious results.

In the second step, the stationarity of the residual series is tested using the ADF unit root test based on a model without a constant and time trend (Asteriou & Hall, 2011), as presented in Eq. (7).

$$\Delta\hat{\varepsilon}_t = \beta_1\hat{\varepsilon}_{t-1} + \sum_{i=1}^{p}\beta_2\,\Delta\hat{\varepsilon}_{t-i} + v_t, \quad (7)$$

where v is the white noise, and p is the lag length of the autoregressive (AR) process, starting from 1, 2, 3, …, i, which is selected based on the lowest values of the Schwarz information criterion (SIC). The null hypothesis of the ADF unit root test is a non-stationary time series. Therefore, if $\hat{\varepsilon}_t$~I(0), the null hypothesis must be rejected at a statistical significance level of 0.05.

In the third step, the study conducted short-run dynamic adjustments using an error correction model based on an autoregressive distributed lag (ARDL) structure, as presented in Eq. (8).

$$\Delta Y_t = \alpha_0 + \beta_1\Delta X_t + \sum_{i=1}^{m}\beta_2\Delta X_{t-i} + \sum_{i=1}^{n}\beta_3\,\Delta Y_{t-i} + \gamma ECT_{t-1} + \varepsilon_t, \quad (8)$$

where n and m are the appropriately distributed lags of the variables, γ is the speed of adjustment returning to equilibrium, and ECT_{t-1} is the error correction term in the previous lag, which is part of the disequilibrium term.

This study employs an analysis of asymmetric price transmission, which assumes that the pass-through effect of price changes is not equal for negative and positive price changes of equal magnitude. The study employed an asymmetric price transmission model based on S. von Cramon-Taubadel and J.P. Loy's (1999) approach, which was initially developed by R. Wolffram (1971) and a simple asymmetric model by J.P. Houck (1977), as shown in Eq. (9).

$$\Delta Y_t = \alpha_0 + \beta_1^+\Delta X_t^+ + \beta_2^-\Delta X_t^- + \sum_{i=1}^{m}(\beta_3^+\Delta X_{t-i}^+) + \sum_{i=1}^{n}(\beta_4^-\Delta X_{t-i}^-) + \varepsilon_t, \quad (9)$$

where β_1^+ and β_3^+ are the short-run positive coefficients, β_2^- and β_4^- are the short-run negative coefficients, ΔX^+ is ΔX for all $\Delta X > 0$ and 0 otherwise, and ΔX^- is ΔX for all $\Delta X < 0$ and 0 otherwise. To test the hypothesis for short-run symmetry or short-run asymmetry of price transmission, the study used the joint F-statistic or Wald ($\chi 2$) test. The null hypothesis (H0) of short-run symmetry can be set as $\beta_1^+ = \beta_2^-$.

Furthermore, an asymmetric error correction representation using the ARDL structure was applied by S. von Cramon-Taubadel and J.P. Loy (1999), which includes ECT_{t-1}^+ and ECT_{t-1}^-. This can be expressed in Eq. (10).

$$\Delta Y_t = \alpha_0 + \beta_1^+\Delta X_t^+ + \beta_2^-\Delta X_t^- + \sum_{i=1}^{m}(\beta_3^+\Delta X_{t-i}^+) + \sum_{i=1}^{n}(\beta_4^-\Delta X_{t-i}^-) + \gamma_1^+ ECT_{t-1}^+ + \gamma_2^- ECT_{t-1}^- + \sum_{i=1}^{p}(\theta_1\Delta Y_{t-i}) + \varepsilon_t, \quad (10)$$

where γ_1^+ and γ_2^- are the positive and negative adjustment coefficients, ECT_t^+ is the ECTt for all $ECT_t > 0$ and 0 otherwise, ECT_t^- is the ECTt for all $ECT_t < 0$ and 0 otherwise, and θ is the coefficient of the lagged dependent variable. To examine the hypothesis of symmetric or asymmetric adjustment of price transmission, the joint F-statistic or Wald (χ^2) test was also utilised. The null hypothesis (H0) of symmetric adjustment can be set as $\gamma_1^+ = \gamma_2^-$.

RESULTS AND DISCUSSION

In time series analysis, testing for data properties such as stationarity or non-stationarity is essential to avoid spurious regression problems caused by the influence of time effects. This study conducted unit root tests on lnP_C, lnP_S, lnP_B, and lnP_E using the ADF and PP methods with a model that included constants and linear time trends. The results, presented in Table 3, were analysed using the natural logarithmic function (ln). The results of the stationarity tests in Table 3 using the ADF and PP unit root methods were consistent. Specifically, at the conventional level, the variables (lnP_C, lnP_S, lnP_B, and lnP_E) failed to reject the null hypothesis (H_0: non-stationarity) at a statistical significance level of 0.05. Thus, it can be concluded that these four variables are non-stationary time series at the level stage and require the addition of the first difference order to the variables before testing for stationarity again. After adding one order of difference to the variables, stationarity tests were conducted using the ADF and PP unit root methods. The results showed that all variables had t-statistics that were significant at a level of 0.01, rejecting the null hypothesis of non-stationarity. Therefore, it can be concluded that all four variables (ΔlnP_C, ΔlnP_S, ΔlnP_B, and ΔlnP_E) are stationary at the first difference or I(1) process based on the ADF and PP unit root tests.

***Table 3**. The results of the ADF and PP unit root tests*

Variable	ADF unit root		PP unit root	
	t-statistic	p-value	t-statistic	p-value
lnP_C	-1.971	0.611	-1.925	0.635
lnP_S	-2.309	0.425	-2.009	0.590
lnP_B	-1.373	0.864	-1.847	0.676
lnP_E	-3.109	0.108	-2.779	0.207
ΔlnP_C	-7.855	<0.001	-7.846	<0.001
ΔlnP_S	-9.330	<0.001	-9.208	<0.001
ΔlnP_B	-10.989	<0.001	-11.223	<0.001
ΔlnP_E	-6.186	<0.001	-11.168	<0.001

***Note:** the null hypothesis (H0) of the ADF and PP unit roots is a non-stationary time series*
***Source:** author's calculation*

Table 4 presents the results of the Granger causality tests used to examine the cross-commodity integration of livestock product prices in Thailand, namely beef cattle (P_C), swine (P_S), broiler chicken (P_B), and chicken egg (P_E) prices. The variables (lnP_C, lnP_S, lnP_B, and lnP_E) were employed in the analysis based on the structure of the multivariate VAR(2) model selected using the lowest value of the AIC. The standard F-statistic was used to detect short-run causality, and the Wald (χ^2) test was used to detect long-run block exogeneity among the variables. These two techniques were used to examine cross-commodity market integration, and the results were applied to analyse price transmission in the next objective of the study.

***Table 4**. The results of the Granger causality tests*

Variable (Y)	Independent variable (X)			
	ΔlnP_C	ΔlnP_S	ΔlnP_B	ΔlnP_E
ΔlnP_C	-	0.076 (0.130)	1.333 (0.690)	0.277 (0.032)
ΔlnP_S	0.814 (0.617)	-	4.353 (2.060)	1.039 (0.428)
ΔlnP_B	0.595 (0.328)	6.110^b (2.754^c)	-	2.044 (0.909)
ΔlnP_E	0.507 (0.338)	7.034^b (5.689^a)	5.573^c (5.215^a)	-

***Note:** the statistical significance levels are denoted by superscripts of a, b, and c for 0.01, 0.05, and 0.1 levels, respectively. The null hypothesis of Granger causality is that "X does not Granger cause Y". The statistical values in parentheses are from the standard F-statistic, while those without parentheses are from the chi-square (χ^2) statistic*
***Source:** author's calculation*

The results in Table 4 indicate that both methods used for the Granger causality tests yielded consistent results with slightly different statistical significance levels. The results reveal three one-way directional relationships that are statistically significant within the range of 0.01 to 0.1 levels. Specifically, the price of broiler chickens (P_B) has a significant impact on the price of chicken eggs (P_E), the price of swine (P_S) has a significant impact on the price of chicken eggs (P_E), and the price of swine (P_S) has a significant impact on the price of broiler chickens (P_B). The results suggest that there exists a market integration across livestock commodities in Thailand, with changes in broiler chicken prices having an impact on changes in chicken egg prices, and changes in swine prices having an impact on changes in both chicken egg and broiler chicken prices.

The results of the market integration analysis, indicating three directions of the pairwise relationship across livestock commodities, from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price, are presented in Table 4. The estimates of the cointegration tests in Table 5 indicate that all models have a long-run equilibrium, as the residual series based on the ADF unit root test in all models are statistically significant within the range of 0.01 to 0.05 levels. This implies that the null hypothesis of non-stationarity can be rejected and that the variables are cointegrated. The long-run elasticities between the pairwise relationships in each model can be summarised as follows. Model 1 shows that a one per cent increase in the price of broiler chickens (P_B) leads to a 0.375 per cent increase in the price of chicken eggs (P_E), while in Model 2, a one per cent increase in the price of swine (P_S) results in a 0.365 per cent increase in the price of chicken eggs (P_E). In the case of Model 3, a one per cent increase in the price of swine (P_S) leads to a 0.196 per cent increase in the price of broiler chickens (P_B).

***Table 5**. The results of the cointegration and error correction model tests*

Variable	Model 1: $\ln P_E$	Model 2: $\ln P_E$	Model 3: $\ln P_B$
α	4.277^a	4.114^a	2.840^a
$\ln P_B$	0.375^a	-	-
$\ln P_S$	-	0.365^a	0.196^a
ADF test (ε_t)	-3.250^a	-4.165^a	-2.229^b
ECT_{t-1}	-0.144^a	-0.218^a	-0.071^b

***Note:** the statistical significance levels are denoted by superscripts of a, b, and c for 0.01, 0.05, and 0.1 levels, respectively*
***Source:** author's calculation*

***Table 6**. The results of the short-run symmetry and symmetric adjustment tests*

Variable	Model 1: $\Delta\ln P_E$	Model 2: $\Delta\ln P_E$	Model 3: $\Delta\ln P_B$
α	0.006	-0.001	<0.001
$\Delta\ln P^+_B$	-0.057	-	-
$\Delta\ln P^-_B$	0.352^a	-	-
$\Delta\ln P^+_S$	-	0.207^b	0.271^a
$\Delta\ln P^-_S$	-	0.123	0.389^a
ECT^+_{t-1}	-0.159^c	-0.233^a	-0.057
ECT^-_{t-1}	-0.153^c	-0.256^b	-0.066
$\Delta\ln P_{E,t-1}$	-	0.155^c	-
$\Delta\ln P_{B,t-1}$	-	-	0.070
$\Delta\ln P_{B,t-2}$	-	-	-0.256^a
Wald (χ^2) test			
$\beta^+_1 = \beta^-_2$	0.057^c	0.170	0.528
$\gamma^+_1 = \gamma^-_2$	0.966	0.019	0.927

***Note:** the statistical significance levels are denoted by superscripts of a, b, and c for 0.01, 0.05, and 0.1 levels, respectively*
***Source:** author's calculation*

The ECT_{t-1} coefficients in all models are statistically significant within the range of 0.01 to 0.05 levels, indicating that the error correction mechanism is present and that the models adjust to long-run equilibrium after a short-run deviation. In the event of any price changes or shocks that affect long-run equilibrium and cause the relationship to deviate from its original equilibrium, the pairwise relationship will adjust to its equilibrium again. Thus, Table 5 can describe the speed of adjustment in all models as follows. The relationship between the prices of chicken eggs and broiler chickens will adjust to equilibrium with a speed of 14.4 per cent, while the speed of adjustment between chicken egg and swine prices is 21.8 per cent, and the speed of adjustment of the relationship between broiler chicken and swine prices is only 7.1 per cent. Table 6 presents the hypothesis tests of short-run symmetry and symmetric adjustment to examine the existence of symmetry and asymmetry in price transmission. The results indicate that the hypothesis of short-run symmetry ($\beta_1^+ = \beta_2^-$) is weakly rejected only in the transmission of broiler chicken price (P_B) to chicken egg price (P_E), but there is no evidence of asymmetric adjustment ($\gamma_1^+ = \gamma_2^-$). Moreover, there is no evidence to support the hypothesis of short-run asymmetry and asymmetric adjustment tests for the transmission from the price of swine (P_S) to chicken egg (P_E) and broiler chicken (P_B) prices.

The results indicate that all variables are stationary at the first order of difference, and three pairwise causal relationships exist: from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price. These findings align with prior research confirming that chicken and pork products are close substitutes in other markets (Andersen *et al.*, 2007). However, beef cattle are not found to be close substitutes for broiler chickens and chicken eggs in Thailand. The study also finds that price transmission in Thailand's livestock market is generally symmetrical, except for a weak statistically significant result in the short-run asymmetry of broiler chicken price to chicken egg price.

Granger causality is a widely recognised empirical technique in the literature for analysing market integration across commodity prices. The causality analysis of this study indicates that three causal relationships of price integration exist in Thailand's livestock market: from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price. These findings are consistent with those of P. Fiszeder and P. Orzeszko (2018), who conducted both linear and non-linear Granger causality tests to examine the relationship between the returns of grains (corn, soybean, and wheat) and livestock commodities (live cattle and lean hogs). Their results revealed non-linearities in the relationship between grain and livestock returns, with mostly a two-way directional causality. Similarly, T. Govdeli (2022) utilised Granger causality tests and found a significant positive impact of oil prices on the prices of agricultural raw materials. Furthermore, the findings of P. Ramoroka and C.L. Muchopa (2022) demonstrated a unidirectional relationship in the grain market, where maize prices significantly affected wheat prices in South Africa.

Additionally, testing for asymmetry in the short-run and long-run price transmission across livestock commodities in Thailand revealed that the price transmission characteristics are symmetrical; that is, no asymmetry in price transmission can be detected among livestock prices. These findings are consistent with those of D.G. Kidane (2022), who found a symmetric relationship across regional grain prices in Ethiopia, with no evidence of asymmetric adjustment. On the other hand, these findings are inconsistent with the conclusions of M. Ben Abdallah *et al.* (2020), who found asymmetric long-run and short-run price transmission for dairy products in Hungary. However, the study by C. Jatuporn (2024) discovered that the transmission of global oil prices to domestic commodity prices in Thailand occurs in different manners. Specifically, the findings from this study indicate that the price transmission of global oil prices to most commodities is generally asymmetric (such as the producer price index, consumer price index, export price index, cassava price, diesel price, and gasohol price). The exception is the oil palm price, which has a symmetric relationship with global oil prices. In contrast, the sugarcane price does not exhibit a correlated relationship with global oil prices.

CONCLUSIONS

Thailand faces the challenge of volatile prices in agricultural commodities, particularly livestock products, due to its high dependence on imported feed raw materials. These raw material costs are susceptible to fluctuations caused by global demand and supply, conflicts in major producing countries, climate change, and variations in livestock prices worldwide. Additionally, animal disease outbreaks and economic instability in Thailand contribute to the volatility of livestock product prices. The study's findings indicate that Thailand's livestock commodities are significantly interdependent. Specifically, the results demonstrate that chicken egg prices are significantly responsive to changes in broiler chicken and swine prices, respectively. This implies that chicken eggs are substitutes in the event of shortages in broiler chickens or swine. Furthermore, the study reveals that broiler chicken prices can respond to changes in swine prices since broiler chickens are also considered substitutes in the event of swine shortages. An interesting finding is that the adjustment level in the chicken-egg market is the most effective. The study indicates that chicken egg prices quickly adjust to shocks, making them the most significant substitute during livestock price fluctuations, such as recent animal disease outbreaks in Thailand, followed by broiler chickens, particularly in the case of swine substitution. Therefore, it can be concluded that chicken eggs are among the most important substitutes for livestock commodities in Thailand due to their shorter production time and suitability as a meat substitute.

This study suggests that chicken eggs and broiler chickens can serve as substitute commodities during domestic livestock price volatility, especially during animal disease outbreaks or shortages of livestock supplies. To prevent inefficiencies in the market, the demand and supply of livestock commodities should be managed to ensure prices do not fluctuate drastically. In the event of excessive fluctuations in domestic livestock commodity prices, stakeholders should procure and supply chicken eggs and broiler chickens to meet consumer demand and bring the market into stability. This study analyses livestock market integration and price transmission in Thailand using data from January 2011 to December 2022. The analysis does not include data from 2023, despite recent improvements in livestock disease outbreaks and sustained demand for livestock products. This exclusion is based on the possibility that 2023 data may reflect a short-term positive response, which might not fully capture long-term market dynamics. Additionally, during this period, Thailand was found to have imported smuggled pork products, leading to distortions in domestic pork prices. These smuggled imports, often priced lower than domestic products, could have affected the prices of other livestock commodities.

Furthermore, future studies should consider incorporating a broader range of factors, including both economic and non-economic indicators, to provide a more comprehensive analysis of the livestock market. Given the findings of this study, subsequent research on Thailand's livestock market should explore the use of non-linear models or other asymmetric methods to test market integration and price transmission. Additionally, it would be beneficial to analyse different market levels – such as farm-gate, wholesale, retail, and export – to gain a deeper understanding of market dynamics.

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CONFLICT OF INTEREST

None.

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Інтеграція міжсировинних ринків та цінова трансмісія у тваринницькому секторі Таїланду

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Анотація. Заміщення товарів і послуг є важливим для підтримки стабільності ринку під час цінових коливань, особливо на ринку тваринництва, де продукти є взаємозамінними. Це дослідження мало на меті проаналізувати ринкову інтеграцію та асиметричну цінову трансмісію щодо цін на продукцію тваринництва в Таїланді. Зокрема, воно було зосереджене на цінах на м'ясну худобу, свиней, курей-бройлерів та курячі яйця, використовуючи дані часових рядів з січня 2011 року по грудень 2022 року. Економетрична методологія включала тести на одиничний корінь для визначення стаціонарності часових рядів, тести причинно-наслідкових зв'язків Грейнджера для виявлення спрямованих взаємозв'язків між цінами на продукцію тваринництва та модель асиметричної цінової трансмісії для перевірки короткострокової асиметрії та асиметричного коригування міжтоварних цін. Результати вказують на три напрямки інтеграції цін на ринку тваринництва Таїланду: від ціни на курей-бройлерів до ціни на курячі яйця, від ціни на свиней до ціни на курячі яйця та від ціни на свиней до ціни на курей-бройлерів. Результати свідчать про те, що цінова трансмісія в Таїланді є симетричною, демонструючи ефективний взаємозалежний зв'язок. Таким чином, отримані дані свідчать про те, що курячі яйця є замінником курей-бройлерів та свиней в умовах цінових коливань, а курей-бройлерів - замінником свиней. Результати також показують, що курячі яйця можуть замінити споживання свиней більшою мірою, ніж курей-бройлерів у випадку Таїланду. Це дослідження підкреслює, що курячі яйця є найефективнішим замінником під час коливань цін на худобу в Таїланді, за ними слідують курчата-бройлери. Таким чином, зацікавлені сторони в ланцюгу постачання продукції тваринництва, такі як політики, підприємці та фермери, повинні розуміти міжтоварну інтеграцію та цінову трансмісію на ринку тваринництва Таїланду. Щоб забезпечити стабільність ринку, зацікавлені сторони повинні управляти попитом і пропозицією на тваринницьку продукцію та закуповувати курячі яйця і курчат-бройлерів під час надмірних коливань внутрішніх цін на тваринницьку продукцію

Ключові слова: слова: ринкова влада; цінова стабільність; регулювання цін; товар; замінник; асиметрія