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The Nonlinear Causal Relationship among Exchange Rate, Processed Food Export, and Processed Food Price in Korea: Focusing on the Moderating Role of Export on Processed Food Price

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The Nonlinear Causal Relationship among Exchange Rate, Processed Food Export, and Processed Food Price in Korea: Focusing on the Moderating Role of Export on Processed Food Price

Abstract:

This study investigates the relationship between exchange rates, processed food exports, and processed food prices in Korea using the threshold cointegration method, the threshold vector error correction model, the threshold vector autoregressive model, the Granger causality test, and the generalized impulse response function. We use yearly data from 1990 to 2024 and find a long-run relationship only in processed food prices and exchange rates. The results of the Granger causality tests and generalized impulse response function show that an increase in the exchange rate leads to a rise in processed food prices when the processed food price is relatively high compared to the exchange rate and the exchange rate is relatively high. However, the depreciation of the currency effect on a rise in processed food prices can be buffered by an expansion of processed food exports. Our findings suggest that a processed food export-promoting policy can play a role in food inflation related to an increase in the exchange rate.

Keywords: Exchange Rate, Nonlinearity, Processed Food Export, Processed Food Price

1. Introduction

Depreciation of currency typically means a rise in prices in goods and services from "exchange rate pass through (ERPT)" (Nasir et al., 2020). There are two possible paths for an increase in the exchange rate with an increase in product and service prices. First, imported products or service prices, which are presented as currency, increase with a depreciation of currency value. Second, overall production costs are expected to increase with currency depreciation due to an increase in imported input costs. Thus, many previous studies have investigated the impact of the exchange rate on inflation and consumer prices.

For example, Husaini and Lean (2021) examined the effect of the exchange rate on the consumer price index (CPI) in Indonesia, Malaysia, and Thailand. They found that currency depreciation causes an increase in the CPI in all those countries. Anh et al. (2021) investigated ERPT in ASEAN countries and found an incomplete exchange rate pass-through for domestic prices. Balcilar et al. (2021) analyzed ERPT in BRICS countries which are composed of eleven emerging countries: Brazil, Russia, India, China, South Africa, Iran, Saudi Arabia, Egypt, Ethiopia, United Arab Emirates, and Indonesia. Their results show that ERPT appears well in periods of high levels of depreciation and recession in BRICS countries.

Several previous studies have investigated ERPT in agricultural products and foods. For instance, Baek and Koo (2010) found that the exchange rate is one of the key factors in the rise in U.S. food prices. The results of Bradshaw and Orden (1990) show mixed evidence for ERPT in agricultural prices. Rezitis (2015) found a bidirectional causal relationship between exchange rates based on the U.S. dollar and 30 international agricultural prices. Reboredo and Ugando (2014) found that depreciation of currency in U.S. dollars did not cause a rapid rise in food prices, except for soybean. Akanni (2020) found that ERPT in food prices in Nigeria

during the crash period affected the exchange rate.

Some previous studies have focused on ERPT, considering the adoption of inflation targeting (I.T.). For example, Nasir et al. (2020) find that ERPT in the Czech Republic, representing a small open I.T. country, is affected by inflation expectations. Pham et al. (2023) compared I.T. countries and non-IT countries to examine the ERPT. Their findings show that the exchange rate causes changes in inflation as well as asymmetric effects of the exchange rate on inflation in Indonesia, the Philippines, and Singapore. The effect of the exchange rate on inflation is different among I.T. countries and non-I.T. countries. Nasir and Vo (2020) investigated ERPT in New Zealand, UK, and Canada. They found that ERPT causes more inflation under I.T. policies than under non-IT policies. In summary, the results of previous studies on ERPT and I.T. did not show consistent results.

ERPT issues might be very important to consistently exchange rate-increasing countries, since if ERPT is shown, inflation will consistently be sustained. Korea is one of the countries that has experienced consistent currency depreciation. According to the Bank of Korea (BOK) database, exchange rates ($1: Korean won) in 1990, 2000, 2010, 2020, and 2024 were 707.97, 1,130.61, 1,156.26, 1,180.05, and 1363.98, respectively. Few previous studies have analyzed ERPT under I.T., focusing on Korea. Prasertnukul et al. (2010) examined ERPT under I.T. in Indonesia, Korea, the Philippines, and Thailand. Their results show that while the ERTP can be reduced by I.T. in Korea and Thailand, it is less clear in Indonesia and the Philippines. Dilla et al. (2017).

Considering that inflation driven by a consistent increase in the exchange rate means a real income reduction, inflation leads to an increase in the burden of purchasing food for low-income groups of people. Between fresh agricultural products and processed food, a rise in the

price effect on the low-income group of people is severe in processed food. This is supported by Sapio et al. (2025), who reported a huge increase in ultra-processed food consumption in many developed countries. Moreover, the U.S. total energy intake is satisfied by approximately 60% by ultra-processed food, and this tendency is more severe in low-income people (Baraldi et al., 2018). Thus, focusing on the ERTP in processed food is important in terms of food security problems in low-income people, which can originate from a rise in food prices.

Previous studies on ERTP in Korea, focusing on food prices, are extremely rare. Seok et al. (2023) investigated the impact of exchange rates on food price comparisons before and after COVID-19 using the asymmetric Autoregressive Distributed Lag (ARDL) model. Considering the extremely low ratio of operating gain to revenue in the processed food sectors in Korea, an increase in the exchange rate effect on processed food prices can be higher than in other sectors. According to the Korea Investor's Network for Disclosure System (KIND) data, the profit margin of publicly traded food companies is 4.97% in 2024. Thus, it is important to control for a possible increase in processed food prices in Korea from currency depreciation.

One possible way to reduce the increase in processed food prices from an increase in the exchange rate is exports. It is because food companies in Korea uses only 31.9% (Based on usage amount) domestic ingredients in 2023 according to "2024 Survey on Raw Material Consumption in the Food Industry" report from Korea Agro-Fisheries & Food Trade Corporation. In other words, processed food companies' operating gain to revenue is heavily dependent on the price of imported ingredients, which is affected by the exchange rate. However, if these food companies export more by currency depreciation, their earnings from an increase in the exchange rate might compensate for a rise in costs from imported ingredient prices.

However, to the best of the authors' knowledge, there is no previous study on the ERTP in processed food prices in Korea. Thus, this study investigates the causal relationship between exchange rates, processed food prices, and processed food exports in Korea using yearly data from 1990 to 2024. Specifically, this study utilizes the threshold vector autoregressive model (TVAR), threshold vector error correction model (TVECM), Granger causality test, and generalized impulse response function to analyze a possible nonlinear relationship among exchange rate, processed food price, and processed food exports in Korea.

We assume that the possible nonlinearity among them can be divided into three parts. First, the relationship between the exchange rate and processed food prices can differ according to their relative levels. Depending on the relatively high or low processed food price compared with the exchange rate, the relationship between them is expected to be different. Second, the relationship between processed food prices and exports can differ according to the price level of processed food. If the price level of processed food is low, a change in price is not expected to significantly affect exports. However, if the price level of processed food is high, a change in price is expected to significantly affect exports. Third, the relationship between processed food exports and exchange rates can differ according to the exchange rate. If the exchange rate is high, processed food exports can be significantly increased, based on the price reduction effect. On the other hand, if the exchange rate is low, processed food exports cannot be increased because the price reduction effect is low based on an exchange rate change.

Our approach and results contribute to the literature on exchange rates and consumer prices in several ways. To the best of our knowledge, this study is the first to examine the relationship between exchange rates and processed food prices in Korea, considering the possible moderating role of exports. Second, this study focuses on processed food prices rather

than on overall inflation or price levels, as in most previous studies. This can be a contribution to the literature because low-income people can be affected significantly by changes in processed food prices. Despite the importance of the price level of processed food, there have been few studies on the relationship between the exchange rate and processed food prices in Korea. Third, this study investigated the possible nonlinearity in the relationship between exchange rates, processed food prices, and processed food exports. Based on these approaches, policy implications for managing processed food prices can be developed. For example, depending on the relationship between the exchange rate and processed food price, the causal effect of the exchange rate on processed food prices can be different. The government should focus on the period when these effects appear and are sufficiently high to control the processed food price level. Additionally, depending on the level of processed food prices, the causal effect of processed food exports on processed food prices can be different. Korea should focus on the period when the moderating effect of processed food exports on processed food prices does not appear to keep the processed food price at a stable level.

2. The Korea Processed Food Sector Price and Characteristics

As shown in Figure 1, total and processed food price levels have consistently increased from 1990 to 2024 in Korea. However, in Korea, the growth rate is much higher for processed food prices than for total prices. Specifically, the total growth rates of the total price and processed food price between 1990 and 2024 were 196.73% and 286.15%, respectively. Moreover, the variation in the price of processed food is much higher than the variation in the total price. The growth rate of processed food prices in Korea has increased abruptly from 2007 to 2020. One possible explanation for the rapid increase in processed food prices in 2007 is the

global food crises in 2007 and 2008. Processed food production requires raw agricultural products, which ultimately affect processed food prices. The rapid increase in processed food prices since 2020 can be explained by Covid-19. Hobbs (2020) mentioned that the issue of the resiliency of food supply chains arose during that period. Even though Covid-19 is a common shock to the total and processed food sectors, the price increase effect was much higher in the processed food sector in Korea.

<Insert Figure 1 Here>

Table 1 presents the share of ingredients in the food sector by origin in Korea. Based on the value criteria, the use of domestic ingredients by the food sector in Korea has decreased from 2010 to 2023. Specifically, the domestic ingredient share, based on the value, decreased from 79.4% to 45%. However, the share of domestic ingredients in 2023 is 31.9%, which implies that the Korean food sector will use high-valued domestic ingredients and low-valued imported ingredients. These results indicate that the prices of domestic agricultural products are higher than those of imported agricultural products. Considering the high share of imported ingredients in processed foods, the exchange rate can affect processed food prices in Korea. It is well shown in Figure 2 that presents the relationship between the exchange rate and processed food prices in Korea.

<Insert Table 1 Here>

<Insert Figure 2 Here>

As shown in Table 2, the use of domestic ingredients by the Korean food sector is relatively low in “Grains & Grain Flours”, “Pulses & Tubers”, “Sugars & Edible Oils”, and “Other Materials & Food Products”. In other words, the cost of these ingredients in the Korean food sector can be directly affected by changes in the exchange rate. However, the effect of the exchange rate on food ingredient prices on the relatively higher usage of domestic ingredients might be indirect. This is because farming supplies for domestic agricultural products are imported into Korea. Fertilizers, pesticides, and feeding materials are mostly imported from foreign countries (Kim et al.., 2023).

<Insert Table 2 Here>

Thus, the exchange rate might be a very important factor in determining processed food prices in Korea through both direct and indirect paths. Furthermore, exporting processed food can play a role in moderating the effect of the exchange rate on processed food prices in Korea due to foreign currency earning from exports. This aspect is crucial because the operating profit margin of the Korean food sector is only 4.97% in 2024, according to KIND data. Thus, the direct buffering of a change in the exchange rate by exports might be effective in the food sector of Korea. As the food export growth rate increased between 2007 and 2020, the processed food price growth rate decreased (see. Figure 3).

<Insert Figure 3 Here>

3. Data

This study utilizes yearly data from 1990 to 2024 as our focus of processed food exports on the effect of exchange rate on processed food prices in Korea. We suppose that while an increase in the exchange rate affects the rise of processed food prices due to a low operating profit margin, an increase in processed food exports may compensate for a cost increase from currency depreciation. This compensation mechanism is expected to require a long-term adjustment because processed food companies do not adjust prices according to cost shocks due to the menu price. In this sense, this study used yearly data rather than monthly or weekly data. Table 3 shows specific information for the data used in this study. The proxy variable for processed food prices is the processed food price index (2020=100) gathered from the BOK. The exchange rate measured by $1: Korean won was collected from the BOK. The proxy for processed food exports is calculated by multiplying the GDP and the export share of food.

<Insert Table 3 Here>

Table 4 presents the descriptive statistics for *ER*, *EX*, and *P*. The value of the standard deviation divided by the mean (VM) was the lowest in *the ER*. These values are the highest in *EX*, and the value of *P* is also much higher than *that of ER* in terms of VM. That means that the variation of *EX* and *P* are over the sample period compared to *ER*. These statistics imply that a change in the exchange rate on *EX* or *P* may be effective. The results of the correlations among the *ER*, *EX*, and *P* are presented in Table 5. At the 5% significance level, all possible pairs of

variables have a positive correlation. This indicates a possible causal relationship among *ER*, *EX*, and *P*.

<Insert Table 4 Here>

<Insert Table 5 Here>

4. Empirical Framework

The model selection for estimation is shown in Fig. 4. First, we performed unit root tests based on augmented Dickey–Fuller (ADF) and Phillips-Perron (PP) for *ER*, *EX*, and *P*. Based on the unit root test results, we decided to choose whether to perform the Johansen cointegration test. If the pairs of variables are *I*(0), we will utilize the Johansen cointegration test. If we find a long-run relationship based on the Johansen cointegration test, we examine the threshold cointegrated relationship. If there is a threshold cointegrated relationship between variables, this study uses the threshold vector error-correction model (TVECM). If we do not find a threshold cointegrated relationship between variables, this study utilizes a vector error correction model (VECM). If the pairs of variables are *I*(1), we use the first difference data for the estimation. Specifically, this study tested the nonlinearity between variables based on Lo and Zivot (2001). If nonlinearity exists between variables, we employ the threshold vector autoregressive (TVAR) model. However, if linearity exists between variables, we use a vector autoregressive (VAR) model.

<Insert Figure 4 Here>

4.1. Johansen Cointegration Test and VECM

This study used the Johansen cointegration test for *the ER-EX*, *EX-P*, and *ER-P*. To discuss the Johansen cointegration test and VECM, we present a VAR model as in Chen and Saghaian (2016) and Kim et al. (2018).

$$X_t^j = \gamma^j + \sum_{n=1}^{m+1} \Psi_n^j X_{t-n}^j + \varepsilon_t^j \quad (1)$$

where $j = 1, 2, 3$, X_t^1 is a 2×1 vector for *ER-EX*, X_t^2 is a 2×1 vector for *EX-P*, X_t^3 is a 2×1 vector for *ER-P*, γ^j is a constant vector for pairs of *ER-EX*, *EX-P*, and *ER-P*, the number of lags is *m*+1, ε^j are independent and identically distributed (*i.i.d.*) error terms for pairs of *ER-EX*, *EX-P*, and *ER-P*. Our VAR model can be written as the following VECM:

$$\Delta X_t^j = \gamma^j + \Psi^j \mathrm{X}_{t-1}^j + \sum_{n=1}^{m} \Pi_n^j \Delta X_{t-n}^j + \varepsilon_t^j \quad (2)$$

where, $\Psi^j = \Psi_1^j + \Psi_2^j + \cdots . + \Psi_k^j - I$ and $\Pi_{l=m+1}^p = -\sum_{l=m+1}^p \Psi_l^j$. Ψj can be decomposed Ψ^j into $\Psi^j = \alpha^j (\beta^j)'$. α^j is the adjustment vector $(2 \times r)$, which represents the adjustment speed to long-run equilibrium. And, β^j is the cointegrating vector $(r \times 2)$ which reflects the linear relationship between the two variables. where r represents the rank of the cointegration vector.

To examine the existence of a long-run relationship, we apply the Johansen cointegration test in several steps. First, this study tests the null hypothesis of $r = 0$ and the alternative hypothesis of $r \geq 1$. If we can reject this null hypothesis, we examine the null

hypothesis of $r = 0$ and the alternative hypothesis of $r \geq 2$. These testing procedures were continued if the null hypothesis could be rejected. If two variables are cointegrated, $\Psi^j \mathrm{X}_{t-1}^j$ can be presented as $\alpha^j(\beta^j)'\mathrm{X}_{t-1}^j.(\beta^j)'\mathrm{X}_{t-1}^j$ indicates the error correction term (ECT_{t-1}^j). As Kim et al. (2018) mentioned, if α^j is significant based on a conventional *t*-test, then we can judge long-run Granger causality, which indicates the exogeneity test.

4.2. Long-Run Nonlinearity Test and TVECM

Equation (2), which represents the VECM for our approach, assumes that the adjustment speed to long-run equilibrium is constant. However, the adjustment speed to the long-run equilibrium may not be constant, which means a different adjustment speed to equilibrium. Equation (3) presents three TVECM regimes:

$$\Delta X_t^j = \begin{cases} \gamma_L^j + \alpha_L^j ECT_{L,t-1}^j + \Pi_{L,1}^j \Delta X_{L,t-1}^j + \cdots + \Pi_{L,1}^j \Delta X_{L,t-m}^j + \varepsilon_{L,t}^j, if\ ECT_{t-1}^j > v_1^j \\ \gamma_M^j + \alpha_M^j ECT_{M,t-1}^j + \Pi_{M,1}^j \Delta X_{M,t-1}^j + \cdots + \Pi_{M,1}^j \Delta X_{M,t-m}^j + \varepsilon_{M,t}^j, if\ v_1^j \leq ECT_{t-1}^j \leq v_2^j \\ \gamma_H^j + \alpha_H^j ECT_{H,t-1}^j + \Pi_{H,1}^j \Delta X_{H,t-1}^j + \cdots + \Pi_{H,1}^j \Delta X_{H,t-m}^j + \varepsilon_{H,t}^j, if\ ECT_{t-1}^j > v_1^j \end{cases} \quad (3)$$

where v_1 and v_2 are the threshold values for ECT_{t-1}^j dividing the lower, middle, and high regimes, respectively. *L*, *M*, and *H* indicate lower, middle, and higher regimes, respectively. The utilization of TVECM rather than VECM is justified by Hansen and Seo's (2002) test, which is called the supreme Lagrange Multiplier (*SupLM*) test. The null hypothesis of Hansen and Seo (2002) is the linear VECM, and the alternative hypothesis is the TVECM. To derive the threshold values, the grid search method suggested by Hansen and Seo (2002) was applied.

4.3. Threshold Linearity Test and TVAR

We employ the threshold linearity test method introduced by Lo and Zivot (2001). This test method is an extension of Hansen (1999) and is composed of three tests. The first test examines the alternatives: linear VAR and TVAR with one threshold. The second test is a comparison between the linear VAR and TVAR with two thresholds. The third test compares TVAR with one threshold, and TVAR with two thresholds.

The TVAR model with one threshold can be written as the following equation:

$$X_t^j = \begin{cases} \delta_L^j + \rho_{L,1}^j X_{t-1}^j + \rho_{L,m}^j X_{t-m}^j + u_{L,t}^j, if\ X_{t-d}^j \le \theta_L^j \\ \delta_M^j + \rho_{M,1}^j X_{t-1}^j + \rho_{M,m}^j X_{t-m}^j + u_{M,t}^j, if\ \theta_L^j < X_{t-d}^j < \theta_H^j \\ \delta_H^j + \rho_{H,1}^j X_{t-1}^j + \rho_{H,m}^j X_{t-m}^j + u_{H,t}^j, if\ X_{t-d}^j \ge \theta_H^j \end{cases} \quad (4)$$

where δ_L^j, δ_M^j, and δ_H^j are the intercepts of the low, middle, and high regimes, respectively. The number lag is *m* and θ represents the threshold. The transition variable was expressed as X_{t-d}^j. Threshold values were calculated using the grid search method introduced by Stigler (2010) based on the following objective function:

$$\hat{\theta} = agrmin\ SSR(\theta) \quad (5)$$

4. Results

Table 6 shows the results of two types of unit root tests: ADF and PP. Based on the ADF and PP test results, we found that *P*, *EX*, and *ER* are *I*(1) at the 10% significance level. Thus, we performed the Johansen cointegration test for the three pairs of *ER*-*EX*, *EX*-*P*, and *ER*-*P*. Only the *ER*-*P* has a cointegrated relationship between the variables at the 10% significance level. Specifically, there is a long-run relationship with rank order because we can reject the null hypothesis of *r*=0 and cannot reject *r*=1 at the 10% significance level. In other

words, we do not find a long-run relationship between the pairs of *EX*-*P* and *EX*-*ER*. Thus, this study applies TVEM for *ER*-*P* with a rank order of one, and TVAR for *EX*-*P* and *EX*-*ER*.

<Insert Table 6 Here>

<Insert Table 7 Here>

The results of *the supLM* test and TVECM for *ER*-*P* are presented in Table 8. Based on the results of *the supLM* test, this study found that *ER* and *P* have a nonlinear relationship due to the rejection of the null hypothesis with a linear relationship between them at the 10% significance level. The error correction terms were significant only in Regime 3 at the 10% significance level. Specifically, the coefficients for ECT_{t-1} for the equations of *ER* and *P* are 1.4225 and 0.5600 in Regime 3. These results indicate that *ER* and *P* have a bidirectional long-run Granger causation relationship according to long-run weak exogeneity, as suggested by Granger (1988). Considering the positive coefficient values of ECT_{t-1} in regime 3, *ER* and *P* deviate from a long-run equilibrium if there is disequilibrium. We also performed a short-run Granger causality test for each regime. Table 9 presents the results of the short-run Granger causality test.

<Insert Table 8 Here>

<Insert Table 9 Here>

Figure 5 represents the generalized impulse response function (GIRF) and cumulative GIRF based on the long- and short-run Granger causation relationship. A one-standard-deviation shock of *P* causes negative consequences for *the ER* in all regimes. The absolute effect is highest in regime 3, which presents a relatively high processed food price compared to the exchange rate. These results indicate that an increase in processed food prices affects the decline in the exchange rate. One possible explanation is that a price increase in processed food might cause a decrease in real income, which is expected to lead to lower consumption of imported products. This phenomenon is severe when the price of processed food is higher than the exchange rate. In regime 3, a one-standard-deviation shock to *the ER* causes positive consequences on *P*. This result implies that an increase in the exchange rate might increase the processed food price when the processed food price is relatively high compared to the exchange rate.

<Insert Figure 5 Here>

The results of the TVAR for $\Delta P - \Delta EX$ are shown in Table 10. By selecting the threshold variable as ΔP, we found that there is one threshold between ΔP and ΔEX based on the results of the Likelihood Ratio (LR) test. The threshold value of ΔP was 0.04539354, and the relationship between ΔP and ΔEX appeared strong in regime 2 with $\Delta P > 0.04539354$. To test the causal relationship, we performed the Granger causality test, the results of which are shown in Table 11. Similar to the TVAR result, ΔP and ΔEX have bidirectional Granger causation only in Regime 2. Based on these Granger causality test results, we also performed a GIRF and cumulative CIRF, as shown in Figure 6. A one-standard-

deviation shock of ΔP causes positive consequences for ΔEX in Regime 2. This result implies that an increase in processed food prices leads to an increase in processed food exports when the size of the processed food price increase is relatively high. One possible explanation is that a rise in processed food prices is expected to increase export values if the export volume is the same. A one-standard-deviation shock of ΔEX causes negative consequences for ΔP in Regime 2. This result indicates that an expansion in processed food exports leads to a decline in processed food prices. This result implies the moderating role of processed food exports on processed food prices when the size of processed food price increases is relatively high.

<Insert Table 10 Here>

<Insert Figure 6 Here>

The results of the TVAR for $\Delta ER - \Delta EX$ are shown in Table 12. By selecting the threshold variable as ΔER, we found that there is one threshold between ΔER and ΔEX based on the result of the Likelihood Ratio (LR) test. The threshold value of ΔER is 0.04539354, and the relationship between ΔP and ΔEX appears strong in regime 2, with $\Delta ER > 0.02764816$. To test the causal relationship, we performed the Granger causality test, the results of which are shown in Table 13. Similar to the TVAR result, ΔER has a unidirectional Granger causation on ΔEX in Regime 2. Based on these Granger causality test results, we also performed a GIRF and cumulative CIRF, as shown in Figure 7. A one-standard-deviation shock of ΔER causes positive consequences for ΔEX in Regime 2. This result indicates that currency depreciation increases processed food exports.

<Insert Table 12 Here>

<Insert Table 13 Here>

<Insert Figure 7 Here>

5. Conclusion and Policy Implications

This study investigates the relationship between exchange rates, processed food exports, and processed food prices in Korea using yearly data from 1990 to 2024. We focused on the moderating role of processed food exports on the relationship between the exchange rate and processed food prices. This study expects the moderating role of processed food exports on ERTP to be due to the very low profit margin of food companies. Even though imported ingredient prices are expected to increase with an increase in the exchange rate, if food companies export more, they can compensate for the rise in cost from imports of ingredients. Furthermore, we expect that the pairs of *ER*-*P*, *ER*-*EX*, and *P*-*EX* have a nonlinear relationship. Thus, we utilize TVAR and TVECM to analyze these pairs to examine nonlinearity. Additionally, this study uses the Granger causality test method for these pairs and the GIRF to check the effect based on the Granger causality test results.

The results of the Johansen cointegration test show that only the *ER*-*P* pair of has a long-run relationship. As expected, all pairs show nonlinearity based on the results of *the SupLM* and *LR* tests for the threshold. The exchange rate leads processed food prices in terms of Granger causation in regime 3 for relatively high processed food prices compared to

exchange rates. GIRF and cumulative GIRF show a positive consequence of exogenous shock of *ER* on *P* in Regime 3. The change in processed food prices plays a role in the nonlinearity between processed food prices and exchange rates. In regime 2, for a higher processed food price change period, *P* and *EX* have a bidirectional Granger causal relationship. While the exogenous shock of *P* has a positive consequence on *EX*, the exogenous shock of *EX* has a negative consequence on *P* based on GIRF and cumulative GIRF in regime 2. The change in the exchange rate has a role in the nonlinearity between the exchange rate and processed food exports. Regime 2 has a higher exchange rate period. *ER* had a unidirectional Granger causal effect on *EX*. The exogenous shock of *ER* has a positive effect on *EX* in Regime 2. Considering a positive correlation in pairs of *ER*-*P*, *ER*-*EX*, and *P*-*EX*, processed food exports can have a moderating role in the effect of an increase in the exchange rate on processed food prices in periods of high *ER*, *P*, and *EX*. This is because while an increase in the exchange rate has a positive effect on processed food prices, an increase in exchange rate and processed food exports has a positive effect on processed food exports and processed food prices, respectively. Thus, an increase in the exchange rate effect on processed food prices can be reduced by increasing processed food exports when the exchange rate, processed food exports, and processed food prices are relatively high.

Our approach and results for the relationships between *ER*, *P*, and *EX* provide several policy implications. First, the findings of the moderating role of processed food exports on the effect of exchange rate on processed food prices at a period of relatively high *ER*, *P*, and *EX*. Considering that a stable price level of processed food is very important for food security, especially in middle- and low-income people, promoting processed food exports can be an efficient policy for stable price levels of processed food. In other words, our approach and results suggest that processed food export-promoting policy can play a role in food inflation,

which is related to an increase in the exchange rate.

Second, our results indicate that a rise in processed food prices leads to processed food exports in the regime with a relatively high processed food price. Considering the positive correlation between processed food prices and exchange rates, Korea exports more processed food with a depreciation of currency, even though the absolute price level of processed food is high. This might be possible if a rise in the price effect is less than the depreciation of the currency. The export promotion effect from a rise in price versus the depreciation of currency occurs if food companies' profit margins expand. One possible way to improve export effects in terms of the export promotion effect from a rise in price versus depreciation of currency is to support policies for processed food companies focusing on cost reduction. Therefore, it is important to reduce the rise in processed food prices. The Korean government can reduce the costs of processed food companies by supporting R&D activities for these companies.

Ethics Approval:

Ethics approval was not required for this study as it did not involve human participants, animals, or any clinical interventions. It is based entirely on the analysis of published literature and theoretical frameworks.

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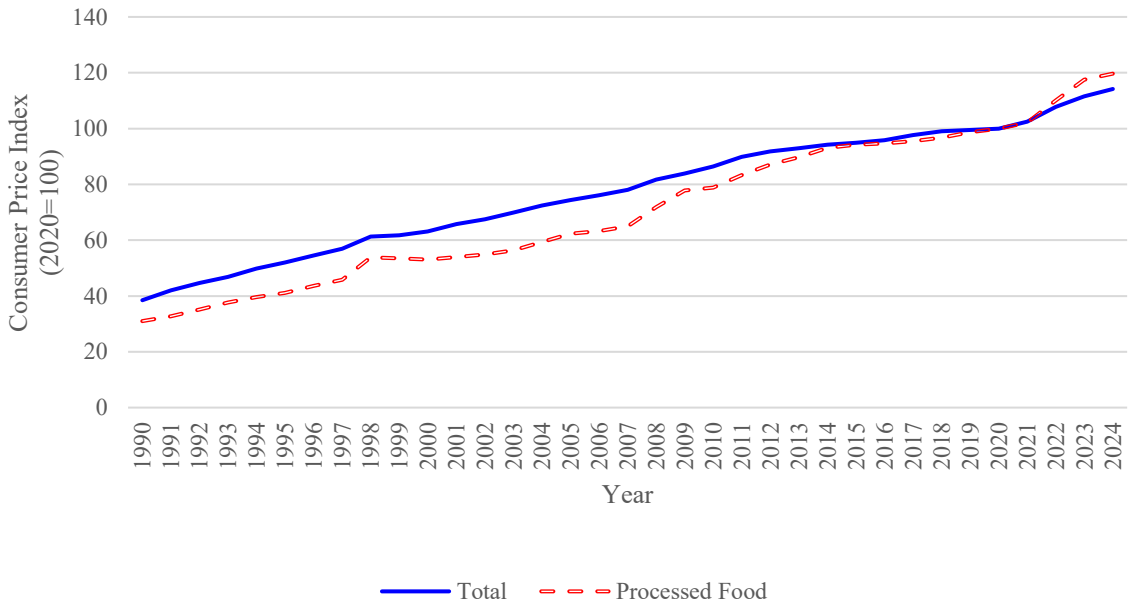


Figure 1. Total and Processed Food Consumer Price Index in Korea (1990-2024)

Source: Bank of Korea

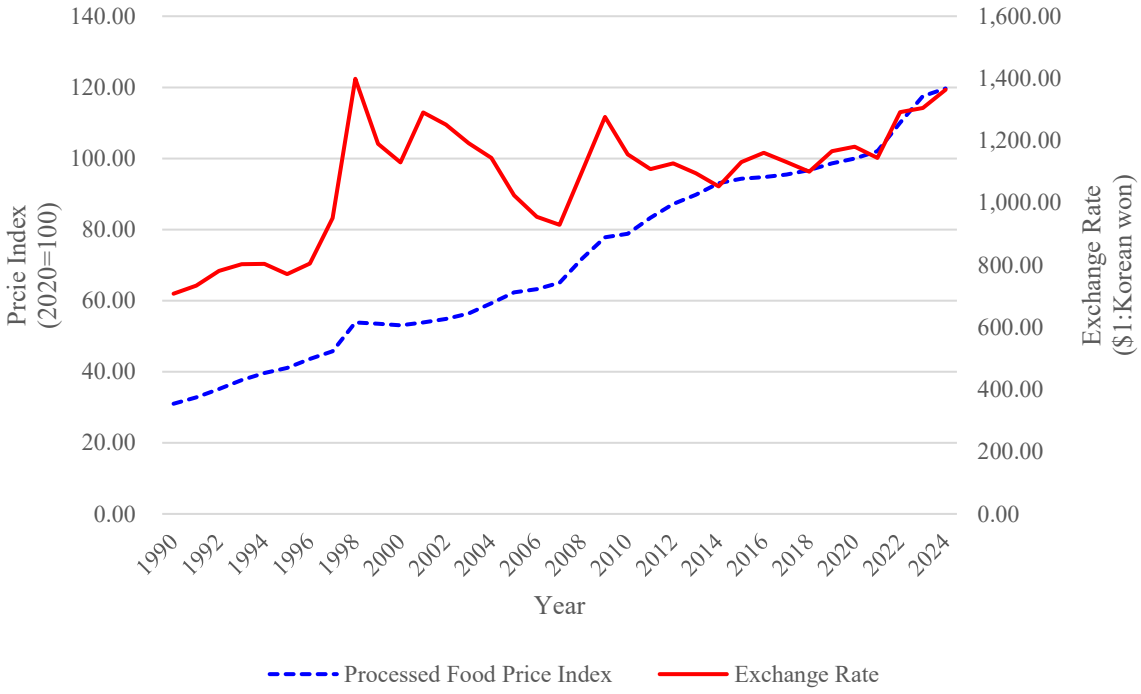


Figure 2. Processed Food Price and Exchange Rate in Korea (1990-2024)

Source: Bank of Korea

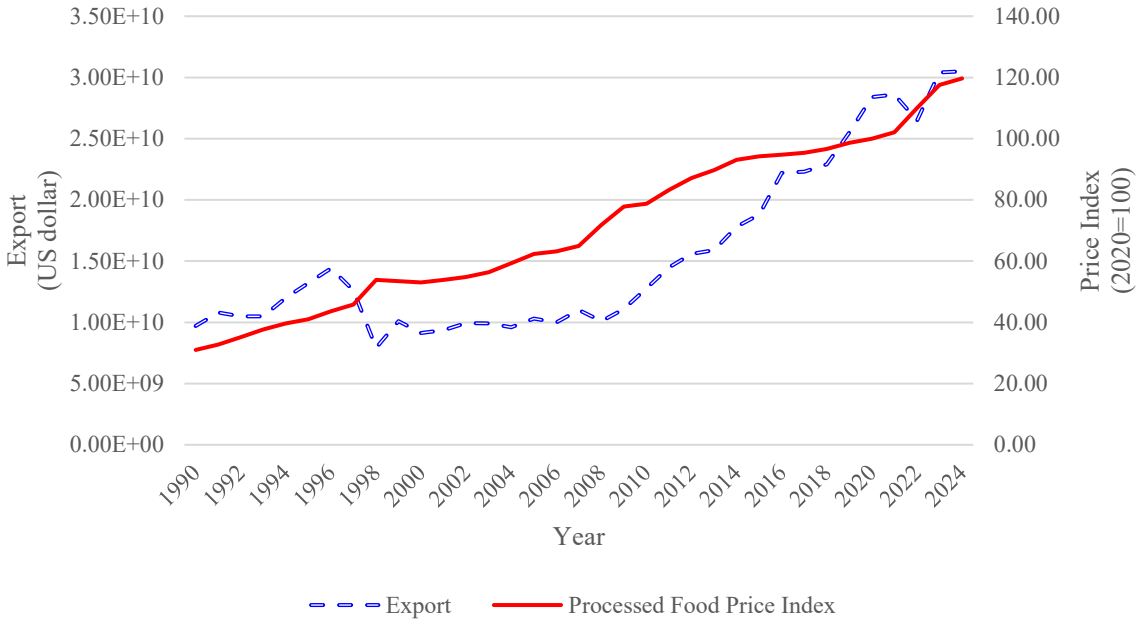


Figure 3. Processed Food Export and Exchange Rate in Korea (1990-2024)

Source: Bank of Korea and World Bank

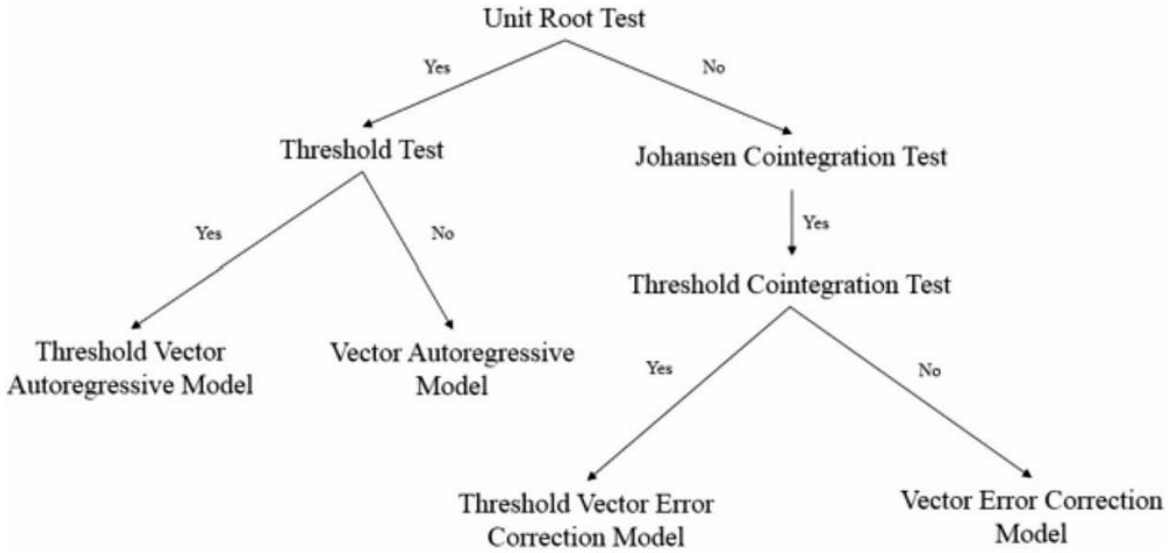


Figure 4. The Flow of Model Selection

Source: Kim et al. (2019) p. 1030.

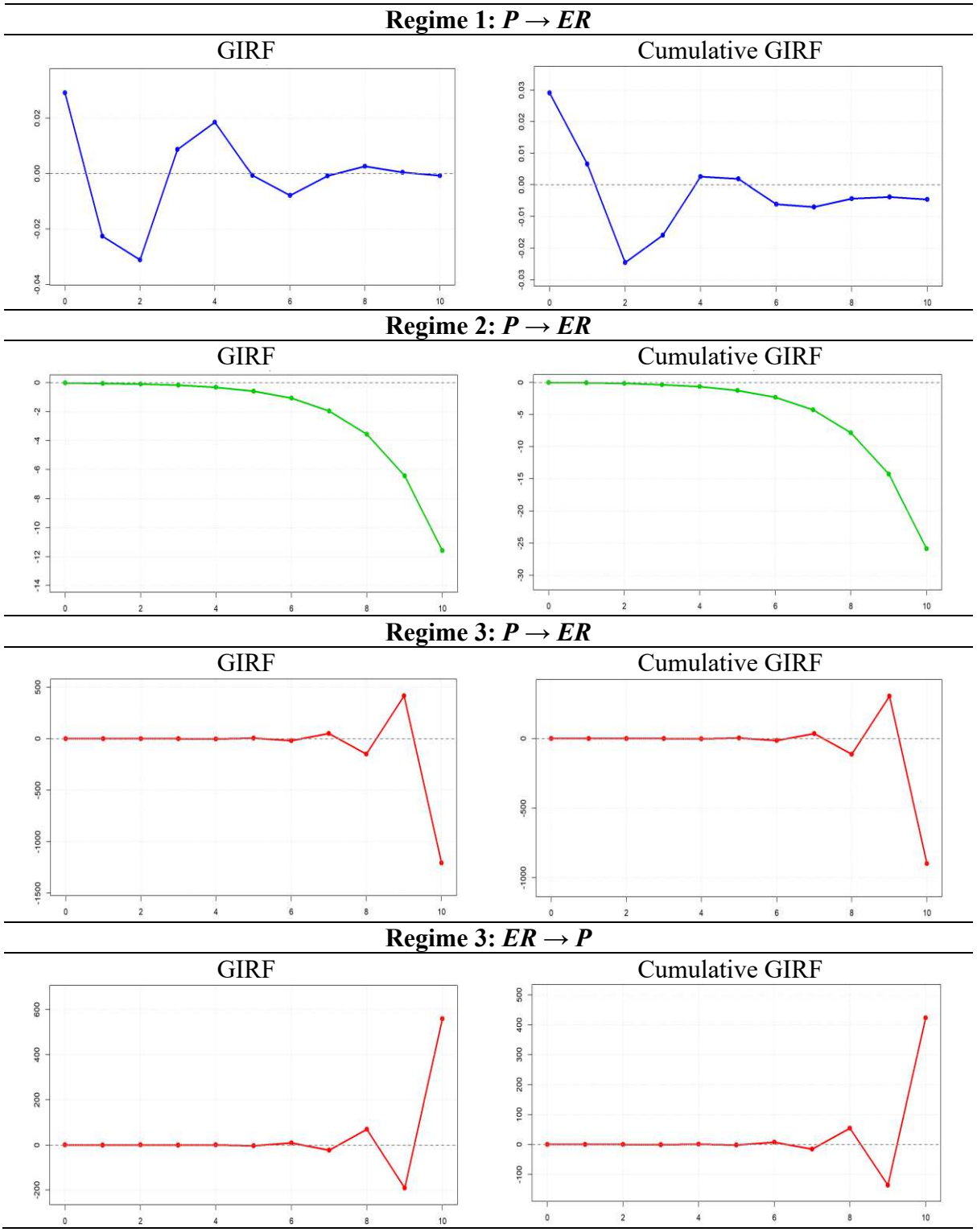


Figure 5. Generalized Impulse Response Function (GIRF) and Cumulative GIRF (*P* – *ER*)

Note: GIRF and Cumulative GIRF are calculated based on 1 standard deviation shock.

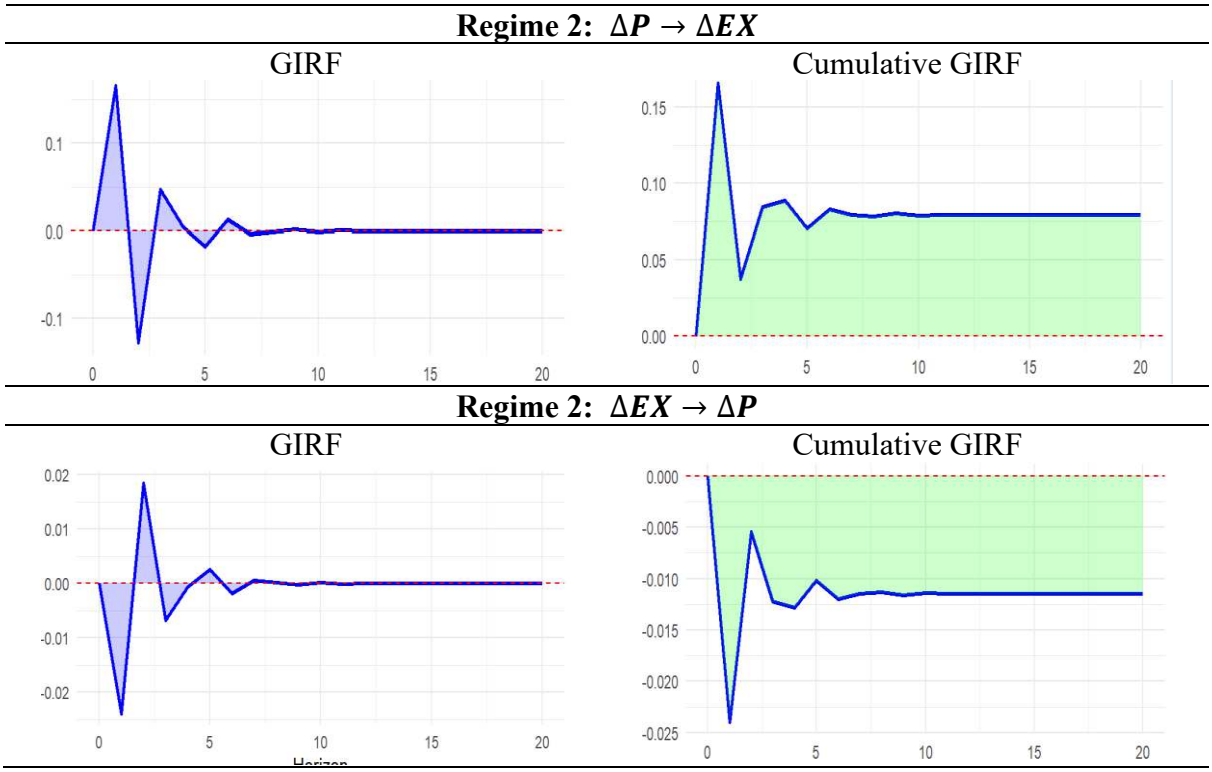


Figure 6. GIRF and Cumulative GIRF from TVAR ($\Delta P - \Delta EX$)

Note: GIRF and Cumulative GIRF are calculated based on 1 standard deviation shock.

Regime 2: $\Delta ER \rightarrow \Delta EX$

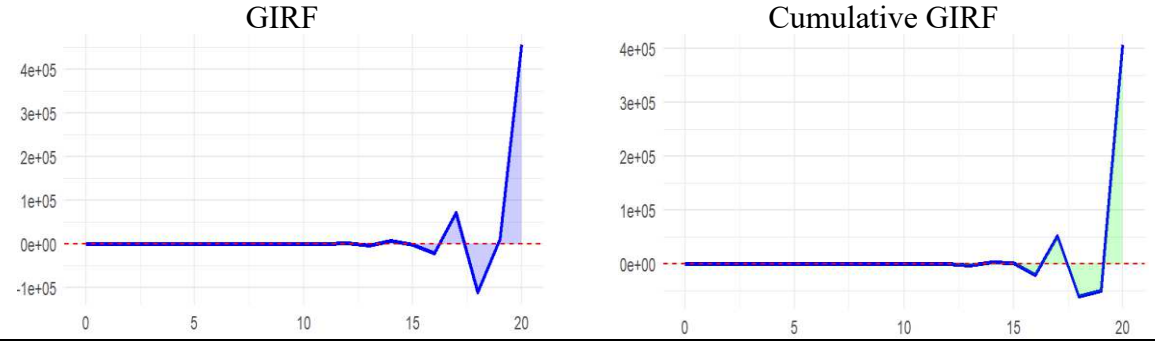


Figure 7. GIRF and Cumulative GIRF from TVAR ($\Delta ER - \Delta EX$)

Note: GIRF and Cumulative GIRF are calculated based on 1 standard deviation shock.

Table 1. Food Sector Ingredients' Share by Origin in Korea

Year	Value Based		Amount Based	
	Domestic Share (%)	Imported Share (%)	Domestic Share (%)	Imported Share (%)
2010	79.4%	20.6%	-	-
2020	46.7%	53.3%	31.9%	68.1%
2023	45.0%	55.0%	31.9%	68.1%

Source: 2011, 2021, and 2024 Survey on Raw Material Consumption in the Food Industry Report in Korea

Table 2. Food Sector Ingredients' Share by Category in Korea

Category	Usage (Tons)	Domestic Share (%)	Purchase Amount (Million Korean Won)	Domestic Share (%)
Total Sum	18,812,817	31.9	30,399,465	45
Grains & Grain Flours	6,929,593	11.2	4,923,289	20.5
Pulses & Tubers	1,594,400	10.1	1,514,642	28.3
Spices & Condiment Vegetables	304,360	74.1	1,114,484	78.3
Special Crops	62,818	38.9	1,328,154	83.6
Fruits & Vegetables	447,219	81	386,400	86.1
Livestock Products & Related Materials	948,843	66.1	5,178,719	64.9
Milk & Dairy Products	2,473,071	94.2	4,115,084	83.1
Marine Products & Related Materials	693,982	67	1,556,128	77.7
Sugars & Edible Oils	3,124,357	2.6	2,900,432	2.3
Other Materials & Food Products	2,234,174	5.4	7,382,133	2.3

Source: 2024 Survey on Raw Material Consumption in the Food Industry Report (p. 52-54) in Korea

Table 3. Explanations for Variables

Variable	Variable	Period	Data Source	Explanation
P	Processed Food Price	1990-2024	Bank of Korea	Processed Food Price Index (2020=100)
EX	Processed Food Export	1990-2024	Bank of Korea	GDP × Export Share of Food
ER	Exchange Rate	1990-2024	Bank of Korea, World Bank	Exchange Rate ($1 : Korean won)

Table 4. Descriptive Statistics

Variable	Obs	Mean	Std. dev.	Min	Max	(Std. dev)/Mean
ER	35	1,078.73	187.54	707.97	1,398.88	0.173851
EX	35	15,600,000,000.00	7,060,000,000.00	7,920,000,000.00	30,500,000,000.00	0.452564
P	35	71.22	26.05	31.00	119.68	0.365731

Table 5. Correlation Matrix among Variables

	ER	*EX*	*P*
ER	1.0000		
EX	0.3759 **	1.0000	
	0.0261		
P	0.6600 ***	0.8516 ***	1.0000
	0.0000	0.0000	

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table 6. Results of Unit Root Tests

Variable	Test	Intercept	Intercept and Trend
		Statistics	Statistics
P	ADF	0.483	-2.544
	PP	0.776	-1.945
ER	ADF	-2.265	-2.781
	PP	-2.169	-2.677
EX	ADF	1.093	-0.934
	PP	1.010	-0.901
ΔP	ADF	-4.400 ***	-4.437 ***
	PP	-4.400 ***	-4.437 ***
ΔER	ADF	-5.698 ***	-5.613 ***
	PP	-5.698 ***	-5.613 ***
ΔEX	ADF	-5.759 ***	-6.440 ***
	PP	-5.759 ***	-6.440 ***

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table 7. Results of Johansen Cointegration Test

	Trace Test	
	r=0	r=1
ER-P	21.83 **	4.88
P-EX	12.91	5.53
EX-ER	15.72	2.55

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively. The optimal lag is chosen using the Akaike Information Criterion (AIC).

Table 8. Results of TVECM

	Regime 1 (56.20%) $ECT \leq -0.03273875$		Regime 2 (21.90%) $-0.0328 < ECT \leq 0.4623$		Regime 3 (21.90%) $ECT > 0.4623$	
	ΔER_{t-1}	ΔP_{t-1}	ΔER_{t-1}	ΔP_{t-1}	ΔER_{t-1}	ΔP_{t-1}
ECT_{t-1}	0.0295	0.0597 *	-0.0967	0.2438	1.4225 **	0.5600 **
	(0.7271)	(0.0587)	(0.8631)	(0.2271)	(0.0380)	(0.0221)
Intercept	0.0431	0.0604 **	0.0516	-0.0904	-0.7996 **	-0.2741 **
	(0.4839)	(0.0123)	(0.8926)	(0.5037)	(0.0293)	(0.0325)
ΔER_{t-1}	-0.2719	-0.1894	2.6351	-0.5201	3.3090 ***	1.0658 ***
	(0.3913)	(0.1007)	(0.1352)	(0.3871)	(0.0003)	(0.0007)
ΔP_{t-1}	1.4303	0.7653 **	-4.3547	1.6460	-14.2576 ***	-4.7403 ***
	(0.1169)	(0.0231)	(0.1624)	(0.1341)	(0.0003)	(0.0005)
ΔER_{t-2}	-0.0391	0.0726	-1.6730	0.0938	2.3056 **	0.8397 **
	(0.8940)	(0.4836)	(0.1189)	(0.7943)	(0.0183)	(0.0149)
ΔP_{t-2}	-1.6557 *	-0.6841 *	6.0452 *	-0.8406	8.9597 ***	3.0304 ***
	(0.0943)	(0.0528)	(0.0695)	(0.4486)	(0.0000)	(0.0000)
Cointegration Vector			(1, -1.6654)			
SupLM Test			20.33**			
Threshold Parameter			Threshold 1: -0.0328 / Threshold 2: 0.4623			

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively. The null hypothesis for *SupLM* test is linear cointegration and the alternative hypothesis is nonlinear cointegration. The optimal lag and number of thresholds were chosen using AIC.

Table 9. Short-run Granger Causality Test Results from TVECM (*ER-P*)

Regime 1			
Null Hypothesis	Statistics		*P*-value
P does not cause *ER*	1.7946	*	0.0943
ER does not cause *P*	1.7575		0.1007
Regime 2			
Null Hypothesis	Statistics		*P*-value
P does not cause *ER*	1.9656	*	0.0695
ER does not cause *P*	0.8926		0.3871
Regime 3			
Null Hypothesis	Statistics		*P*-value
P does not cause *ER*	5.8029	***	0.0000
ER does not cause *P*	4.3623	***	0.0007

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table 10. Results of TVAR between Processed Food Price and Export

	Regime 1: 57.60% $\Delta P \leq 0.04539354$			Regime 2: 42.40% $\Delta P > 0.04539354$			
Variable	ΔP		ΔEX	ΔP		ΔEX	
Constant	0.0175		0.0371	0.1642	***	-0.4333	***
	(0.0119)		(0.0436)	(0.0309)		(0.1139)	
ΔP_{t-1}	0.9204	*	0.6016	-1.6107	***	6.512	***
	(0.4697)		(1.7293)	(0.4277)		(1.5745)	
ΔEX_{t-1}	-0.0534		-0.1801	-0.2556	***	0.8382	***
	(0.0848)		(0.3120)	(0.0807)		(0.2972)	
LR Test for Threshold in ΔP							
1 vs 2	24.87489***						
1 vs 3	44.40879						
2 vs 3	19.53389						

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively. The null hypothesis for *LM* test of "1 vs 2," "1 vs 3," and "2 vs 3" are no threshold versus on one threshold, no threshold versus on two threshold, and one threshold versus on two thresholds, respectively. The optimal lag and number of thresholds were chosen using the AIC.

Table 11. Granger Causality Test Results from TVAR ($\Delta P - \Delta EX$)

Regime 1		
Null Hypothesis	Statistics	*P*-value
ΔP does not cause ΔEX	0.3479	0.7304
ΔEX does not cause ΔP	-0.6297	0.5336
Regime 2		
Null Hypothesis	Statistics	*P*-value
ΔP does not cause ΔEX	4.1359 ***	0.0003
ΔEX does not cause ΔP	-3.1673 ***	0.0035

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table 12. Results of TVAR between Exchange Rate and Processed Food Export

	Regime 1: 71% $\Delta ER \leq 0.02764816$		Regime 2: 29% $\Delta ER > 0.02764816$	
Variable	ΔER	ΔEX	ΔER	ΔEX
Intercept	0.014	0.0273	0.6113	-1.0171 *
	(0.0334)	(0.0366)	(0.4442)	(0.4870)
ΔER_{t-1}	0.5084	0.1054	-6.0160	11.1603 **
	(0.4861)	(0.5329)	(3.6029)	(3.9501)
ΔEX_{t-1}	0.2125	-0.0804	-2.9871 *	5.2801 ***
	(0.2982)	(0.3270)	(1.6354)	(1.7930)
ΔER_{t-2}	-0.3863	0.0514	2.8509 **	-5.4301 ***
	(0.2500)	(0.2741)	(1.2375)	(1.3568)
ΔEX_{t-2}	-0.1475	0.1743	1.3173	-1.1149
	(0.2102)	(0.2305)	(0.8586)	(0.9414)
ΔER_{t-3}	0.1953	0.1339	-3.0780 **	4.9255 ***
	(0.2143)	(0.2349)	(1.3496)	(1.4796)
ΔEX_{t-3}	-0.0661	0.1442	0.1064	-0.5902
	(0.1806)	(0.1980)	(0.7064)	(0.7745)
LR Test for Threshold in ΔER				
1 vs 2	51.83084***			
1 vs 3	93.98475			
2 vs 3	42.15391			

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively. The null hypothesis for *LM* test of "1 vs 2," "1 vs 3," and "2 vs 3" are no threshold versus on one threshold, no threshold versus on two threshold, and one threshold versus on two thresholds, respectively. The optimal lag and number of thresholds were chosen using the AIC.

Table 13. Granger Causality Test Results from TVAR ($\Delta ER - \Delta EX$)

Regime 1		
Null Hypothesis	Statistics	*P*-value
ΔER does not cause ΔEX	0.3992	0.9404
ΔEX does not cause ΔER	1.1342	0.7688
Regime 2		
Null Hypothesis	Statistics	*P*-value
ΔER does not cause ΔEX	35.0814 ***	0.0000
ΔEX does not cause ΔER	5.7128	0.1265

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

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