An Analysis on Non-linear Structure of Livestock Prices Caused by Infectious Diseases:

An Application to Pork, Chicken, and Egg in Korea

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Introduction

The infectious diseases in livestock such as Foot Mouth Disease (FMD) and Highly Pathogenic Avian Influenza (HPAI) can disturb the market of livestock products because they may cause considerable social costs such as the expenses for disinfection and subsidies for damaged farmers. In addition, the occurrence of infectious diseases in livestock increases the price of the livestock products because of the reduction of supply in livestock products, so that they can intensify the price volatility of livestock products. In the same context, the infectious diseases aggravate the income instability of livestock farmers directly and indirectly. For example, in December 2016, 14.66 million poultry were slaughtered due to the HPAI in Korea. Especially, since the damage of layer chicken farms was so huge, the price of a tray of 30 eggs increased from 5,400 KRW[1] to 9,500 KRW in a month.

Due to the increased consumer's interest in food safety, the occurrence of infectious diseases in livestock has an immediate negative effect on the demand for livestock products (Gim et al., 2015). This means that the infectious diseases in livestock affect both the supply and the demand of livestock products. For this reason, the infectious diseases in livestock can cause nonlinear structure in the price of livestock products, which intensifies the price volatility of livestock products and hinders the effectiveness of price stabilization policy for producers and consumers. The purpose of this study is to estimate the impact of the occurrence of infectious diseases in livestock, such as FMD and HPAI, on the nonlinear price structure of livestock products. Specifically, we focus on prices in different distribution channels of the pigs, broilers, and eggs with relatively high frequency of the infectious diseases in livestock.

Previous literature on the infectious diseases in livestock and the price of livestock products have mainly focused on the economic impact of the Bovine Spongiform Encephalopathy (BSE). Leeming and Turner (2004) analyzed the impact of BSE, which took place in 1996, on cattle, sheep and pig price in the UK. For the analysis, OLS (Ordinary Least Square), 2-SLS (Two-step Least Square) and 3-SLS (3-step Least Square) model are used to solve the problem of endogeneity in price data. The results found that the BSE affects the price of beef negatively and affects the price of lamb positively. Lloyd et al. (2006) analyzed the economic impact of BSE on wholesale and retail beef prices in the UK. The monthly retail and wholsale price data for beef, pork, and lamb from January 1990 to December 2000 were applied to the VAR model. They showed that if there exists the market dominance in the market, the exogenous shocks, such as BSE, affect the demand at the retail level and supply at the farm level. McCluskey et al. (2005) estimated the WTP(Willingness To Pay) of Japanese beef that has been tested for BSE and estimated the factors affecting the beef price premium through surveys for Japanese consumers. The results showed that the incidence of BSE decrease beef consumption and increase the WTP for woman to

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[1] Korea Won

beef that has been tested for BSE. However, these studies have mainly focused on the economic impacts of BSE, there are few studies examining the impact of infectious diseases in other livestock on prices in livestock products.

Methodology

In this study, we use Threshold Vector Autoregressive (TVAR) model and Threshold Vector Error Correction Model (TVECM) to identify the nonlinear structure of the livestock product prices caused by the infectious diseases in livestock. Both models rely on the threshold model, an analytical method dividing a sample into two or more regions according to the threshold values when the subject has a nonlinear relationship (Zapata and Gauthier, 2003).

TVAR model is based on the Vector Autoregressive (VAR) model with threshold effects. A single TVAR model with one threshold value is shown in the following equation (1) (Hansen, 2000).

$$Y_t = \begin{cases} c_1 + \beta_{1j} X_t + \epsilon_{1t} & if \;\; q_t < \gamma_i \\ c_2 + \beta_{2j} X_t + \epsilon_{2t} & if \;\; \gamma_i \leq q_t \end{cases} \tag{1}$$

where, $X_t = \left[Y_{t-1}\, Y_{t-2}\, Y_{t-3} \cdots Y_{t-p}\right], \;\; Y_t = [P_1\, P_2\, P_3]$

Y_t is a dependent variable vector, and q_tT is a threshold time series variable. The VAR model can be divided into two or more regimes based on γ_i which is the threshold value. This is summarized in the following equation (2) to (3).

$$Y_t = (c_1 + \beta_1 X_t + \epsilon_{1t}) I(q_t < \gamma_i) + (c_2 + \beta_2 X_t + \epsilon_{2t}) I(q_t \geq \gamma_i) \tag{2}$$

$$Y_t = C + \delta X_t(\gamma) + e_t \tag{3}$$

where. $X_t(\gamma) = [X_t I(q_t < \gamma_i) \;\; X_t I(q_t \geq \gamma_i)]', \;\; \delta = [\beta_1\, \beta_2]$

I is an indicator function that has a value of 1 if the condition is satisfied and a value of 0 otherwise. The TVAR model has a nonlinear / discontinuous form because it has different parameter according to the indicator function I, such as β_1 and β_2. Therefore, the appropriate parameter estimation could be derived from the sequential conditional least squares as equation (4) and the threshold value can be estimated the least squares as shown in equation (5) (Hansen, 1997).

$$\hat{\delta}(\gamma) = (\textstyle\sum_{t=1}^{n} X_t(\gamma)X_t(\gamma)')^{-1}(\textstyle\sum_{t=1}^{n} X_t(\gamma)Y_t) \tag{4}$$

$$\widehat{e_t}(\gamma) = Y_t - \hat{\delta}(\gamma)X_t(\gamma)$$

$$\widehat{\sigma_n}^2(\gamma) = \frac{1}{n}\sum_{1}^{n} \widehat{e_t}(\gamma)^2$$

$$\hat{\gamma} = \mathrm{argmin}_{\gamma\in[\overline{\gamma}\,\underline{\gamma}]}\ \widehat{\sigma_n}^2(\gamma) \tag{5}$$

In order for the estimation results to be meaningful, the threshold effects must exist. For this reason, it is necessary to test the threshold effect. However, under the null hypothesis, there is a problem that the threshold value is not identified in testing the threshold effect. As shown in the equation (6), this can be solved through F- test for residuals both under the null hypothesis and under the alternative hypothesis by assuming that the error term e_t follows iid(independent identically distributed). This is because if e_t follows iid, it is possible to approximate for asymptotic distribution through bootstrapping (Hansen, 1997).

$$F_n = n\left(\frac{\widetilde{\delta_n^2}-\widehat{\delta_n^2}}{\widehat{\delta_n^2}}\right),\ \widetilde{\delta_n^2}\text{ is sum of squar residuals under alternative hypothesis} \tag{6}$$

$$F_n(\gamma) = n\left(\frac{\widetilde{\delta_n^2}-\widehat{\delta_n^2}(\gamma)}{\widehat{\delta_n^2}(\gamma)}\right)$$

TVECM also has a form in which the threshold effect is added to the Vector Error Correction Model (VECM). When there exists a cointegrating relationship, VECM assumes that long-run equilibrium relationship is linear, while TVECM assumes that long-run equilibrium is nonlinear. This is because the presence of transection costs and/or fixed adjustment costs may prevent economic agents from correcting the error continuously (Balke and Formby, 1997). The basic VECM is shown the following equation (7).

$$\begin{bmatrix}\Delta P_t^1\\ \Delta P_t^2\\ \Delta P_t^3\end{bmatrix} = \begin{bmatrix}C_1\\ C_2\\ C_3\end{bmatrix} + \textstyle\sum_{i=1}^{n}\begin{bmatrix}\beta_i^{11}\ \beta_i^{12}\ \beta_i^{13}\\ \beta_i^{21}\ \beta_i^{22}\ \beta_i^{23}\\ \beta_i^{31}\ \beta_i^{32}\ \beta_i^{33}\end{bmatrix}\begin{bmatrix}\Delta P_{t-i}^1\\ \Delta P_{t-i}^2\\ \Delta P_{t-i}^3\end{bmatrix} + \begin{bmatrix}\lambda^1\\ \lambda^2\\ \lambda^3\end{bmatrix}[ECT_{t-1}] + \begin{bmatrix}\epsilon_t^1\\ \epsilon_t^2\\ \epsilon_t^3\end{bmatrix} \tag{7}$$

In equation (7), β_i is the short-term price change, λ is the adjustment speed to the long-term average, and ECT_{t-1} is the error correction term. Balke and Formby (1997) extended the VECM by applying the concept of threshold cointegration, which means TVECM. It is assumed that there exists the threshold in ECT, so that the model is a suitable for explaining short- and long-term changes in variables with nonlinear long-run equilibrium. TVECM implies that ECT can be divided into several regions according to the threshold values, so that each region has different adjustment speeds as shown in equation (8) to (9).

$$\begin{bmatrix}\Delta P_t^1\\ \Delta P_t^2\\ \Delta P_t^3\end{bmatrix} = \begin{bmatrix}C_1\\ C_2\\ C_3\end{bmatrix} + \sum_{i=1}^{n}\begin{bmatrix}\beta_i^{11}\ \beta_i^{12}\ \beta_i^{13}\\ \beta_i^{21}\ \beta_i^{22}\ \beta_i^{23}\\ \beta_i^{31}\ \beta_i^{32}\ \beta_i^{33}\end{bmatrix}\begin{bmatrix}\Delta P_{t-i}^1\\ \Delta P_{t-i}^2\\ \Delta P_{t-i}^3\end{bmatrix} + \begin{bmatrix}\lambda_1^1\\ \lambda_1^2\\ \lambda_1^3\end{bmatrix}[ECT_{t-1}] + \begin{bmatrix}\epsilon_t^1\\ \epsilon_t^2\\ \epsilon_t^3\end{bmatrix} \tag{8}$$

$$if\ \ ECT_{t-1} < \gamma$$

$$\begin{bmatrix}\Delta P_t^1\\ \Delta P_t^2\\ \Delta P_t^3\end{bmatrix} = \begin{bmatrix}C_4\\ C_5\\ C_6\end{bmatrix} + \sum_{i=1}^{n}\begin{bmatrix}b_i^{11}\ b_i^{12}\ b_i^{13}\\ b_i^{21}\ b_i^{22}\ b_i^{23}\\ b_i^{31}\ b_i^{32}\ b_i^{33}\end{bmatrix}\begin{bmatrix}\Delta P_{t-i}^1\\ \Delta P_{t-i}^2\\ \Delta P_{t-i}^3\end{bmatrix} + \begin{bmatrix}\lambda_2^1\\ \lambda_2^2\\ \lambda_2^3\end{bmatrix}[ECT_{t-1}] + \begin{bmatrix}e_t^1\\ e_t^2\\ e_t^3\end{bmatrix} \tag{9}$$

$$if\ \ ECT_{t-1} \geq \gamma$$

It shows that there exists only one threshold in the ECT, so that the model is divided into two regions. In the model, the short-term effects are classified into β_i and b_i, and the adjustment coefficient to long-run equilibrium is also divided into λ_1 and λ_2.

Empirical Data and Results

This study applies TVAR and TVECM to the Korean market in detail using the price of pigs, broilers, and eggs from January 2011 to May 2017 in Korea. Furthermore, we set the infectious diseases data as threshold variables. The price data and the infectious diseases data are obtained from Korea Institute for Animal Products Quality Evaluation (KAPE) and Korea Animal Health Integrated System (KAHIS) in Korea, respectively. The infectious diseases data[2] is used by multiplying the number of infected livestock by the average carcass weight per species. The summary statistics on price data and on diseases are shown in form Table 1 to Table 2.

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[2] Based on the data in KHAIS, pig infectious diseases include FMD (Foot Mouth Disease), PRRS (Porcine Reproductive and Respiratory Syndrome), CSF (Classical Swine Fever), Aujeszky's disease, and Brucellosis. Broiler and laying hens diseases include fowl typhoid, pullorum disease, Newcastle disease, HPAI (Highly Pathogenic Avian Influenza). In the cases of broiler, Tuberculosis is also added.

Table 1. Price summary statistics from 2011 to 2017 (KRW/kg)

	Price	Mean	Std.	Min	Max
Pig	Farm	3,182.50	614.46	1,839	5,170
	wholesale	4,625.77	893.11	2,673	7,515
	Retail	19,023.88	2,521.98	12,214	24,950
Broiler	Farm	1,660.64	316.59	1,048	2,546
	wholesale	3,155.51	431.70	2,196	4,231
	Retail	5,626.39	488.79	4,644	7,123
Egg	Farm	2,024.44	392.27	1,344	3,409
	wholesale	2,228.62	385.64	1,490	3,628
	Retail	2,996.21	406.13	2,285	4,808

Table 2. Disease summary statistics from 2011 to 2017

	Obs.	Occurrences	Mean(kg)	Std. (kg)	Min(kg)	Max(kg)
Pig disease	215	157,814	48,730.97	284,193.8	112.49	3,836,720
Broiler disease	184	2,736,037	11,379.47	46,490.41	3.11	455,003.3
Laying hens disease	103	21,495,268	91,692.49	656,212.5	1.56	7,944,253

Since the models used in this study rely on time series data, the stationarity of the data is verified through the unit root test. As a result of the ADF test, there exist unit root in all prices. Also, it shows that the first difference data of all prices are stationary. Then, the optimal lag is determined based on AIC, SIC, and HQIC statistics. The optimal lag of all livestock products model is 1 as shown in Table 4.

Table 3. Results of Augmented Dickey-Fuller test for unit root

Type	Price		ADF test	
			t-stat.	p-value
Pig	Level	Farm	-0.8709	0.3382
		wholesale	-0.8625	0.3418
		Retail	-0.3023	0.5764
	D(-1)	Farm	-16.211	0.0000***
		wholesale	-16.406	0.0000***
		Retail	-15.681	0.0000***
Broiler	Level	Farm	-1.6742	0.0890*
		wholesale	-0.9904	0.2884
		Retail	-0.6584	0.4315
	D(-1)	Farm	-24.6403	0.0000***
		wholesale	-11.3081	0.0000***
		Retail	-12.5793	0.0000***

Egg	Level	Farm	-1.0386	0.2694
		wholesale	-0.9654	0.2986
		Retail	-0.6391	0.4400
	D(-1)	Farm	-14.5967	0.0000***
		wholesale	-13.0746	0.0000***
		Retail	-18.8839	0.0000***

***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

Table 4. Optimal lag selection

	AIC	SIC	HQIC	Optimal lag
Pig	price (-2) (41.4909)	price (-1) (41.6428)	price (-1) (41.5641)	1
Broiler	price (-7) (43.0791)	Price (-1) (43.3421)	Price (-1) (43.2635)	1
Egg	price (-3) (38.3212)	price (-1) (38.5158)	price (-2) (38.4138)	1

a) The blanket means statistics

Then, we conduct Hansen and Seo (2002) test to test whether there are thresholds in cointegrating relationship considering the threshold cointegration effect established in Balke and Formby (1997). If there are more than one threshold in the error correction term between the distribution channels, which means that long-run equilibrium relationship between the distribution channels has nonlinear structure due to the infectious diseases. In addition, it is necessary to test the threshold cointegration to determine which model is more suitable for analysis among TVAR model and TVECM.

Table 5. Results for Hansen and Seo(2002) cointeration test

	Null hypothesis	Farm to wholesale	wholesale to Retail	Farm to Retail
Pig	t-statistics	4.9407	14.6855	14.4052
	P-value	0.18	0.10	0.10
Broiler	t-statistics	38.7673	32.1415	13.8768
	P-value	0.00***	0.00***	0.24
Egg	t-statistics	15.1331	24.1565	26.7018
	P-value	0.32	0.00***	0.00***

a) ***: $p < 0.01$

The results of threshold cointegraion show that there are no threshold cointegration between the distribution stages' prices of pig. In the case of broiler prices, there are two threshold cointegration both farm to wholesale and wholesale to retail. The result of egg shows that both farm to retail and wholesale to retail are significant. The purpose of this study is to analyze to whether the livestock procducts' prices from farm to retail have a nonlinear structure according to the incidence of infectious diseases, so that TVECM seems to be not appropriate model for analysis because it is not able to grasp the relation of prices of the entire distribution stages. On the other hand, TVAR model can consider the interaction of prices of the entire distribution stages, so we conduct analysis based on TVAR model.

In order to validate threshold model, Hansen (1999) showed that the threshold effects should exist in the VAR model composed of prices for distribution stages as shown in Table 6.

Table 6. Results for threshold effects test

		LR-statistics	P-value
Pig	Linear VAR vs. 1 threshold VAR	28.98	0.12
	Linear VAR vs. 2 threshold VAR	100.92	0.02**
Broiler	Linear VAR vs. 1 threshold VAR	44.17	0.01**
	Linear VAR vs. 2 threshold VAR	101.92	0.03**
Egg	Linear VAR vs. 1 threshold VAR	70.01	0.00***
	Linear VAR vs. 2 threshold VAR	114.57	0.00***

a) ***: $p < 0.01$, **: $p < 0.05$

b) Bootstrapping repeats 100 times

The results of the threshold effects test represent that VAR model for prices of distribution stages has two thresholds for infectious diseases, which means that VAR model would be divided into three regimes due to infectious diseases. Considering the above, the results of TVAR with two thresholds are represented in Table 7 to Table 9.

Table 7. Results of TVAR model for pig

	Farm price	wholesale price	Retail price
regime 1	Pig diseases ≤ 812.1278kg		
Farm price(-1)	0.5382 (0.3895)	0.7895 (0.5643)	1.7205 (2.8837)
wholesale price(-1)	0.2956 (0.2695)	0.4243 (0.3905)	-0.0684 (1.9955)
Retail price(-1)	-0.0291*** (0.0076)	-0.0413*** (0.0110)	0.3864*** (0.0560)
c	655.7839*** (101.2629)	932.3193*** (146.7106)	6,451.8378*** (749.7696)
regime 2	812.1278kg < Pig diseases ≤ 1,278.733kg		

Farm price(-1)	-406.8953*** (65.7822)	-591.6832*** (95.3058)	-3,103.2220*** (487.0636)
wholesale price(-1)	280.9183*** (45.2660)	408.4941** (65.5817)	2138.0734*** (335.1575)
Retail price(-1)	-0.1207*** (0.0201)	-0.1755*** (0.0292)	-0.5419*** (0.1490)
c	974.9594** (454.9076)	1,418.2307** (659.0737)	15,938.3320*** (3368.2200)
regime 3	Pig diseases > 1,278.733kg		
Farm price(-1)	-10.0156 (23.7271)	-14.4539 (34.3760)	112.2430 (175.6799)
wholesale price(-1)	7.6053 (16.3222)	10.9828 (23.6477)	-76.7311 (120.8523)
Retail price(-1)	-0.0338** (0.0166)	-0.0490** (0.0240)	0.8278*** (0.1229)
c	496.2407** (211.3994)	720.1629** (306.2771)	873.2963 (1565.2401)

a) ***: $p < 0.01$, **: $p < 0.05$

b) The blanket means standard error

The threshold values for pig TVAR model in Table 7 are estimated to 812,1278 kg and 1,278.733 kg. In regime 1 where the pig diseases are less than 812.1278 kg, constant and retail price are reject the null hypothesis. Specifically, the retail lag price has a negative impact on the farm price and retail price, also it has negative impact on the wholesale price in regime 1. All of the lag price is significant in regime 2, where the pig diseases are between 812.1278 kg and 1,278.733 kg. The farm and retail lag prices have negative impacts on all prices, and the wholesale lag price has a positive impact on all prices. In regime 3 where the pig diseases are over 812.1278 kg, the retail lag price has a negative impact on farm and wholesale price, and has a positive impact on retail price.

The threshold values for broiler TVAR model in Table 8 are estimated to 3,600 kg and 8016 kg. The farm lag price has a positive impact on all prices in regime 1 where the broiler diseases are less than 3,600 kg. In the regime 2, the wholesale lag price affects positively on all prices, and besides the farm lag price has a negative effect on retail price. In the regime of highest incidence of diseases for broiler, only the wholesale lag price is statistically significant.

Table 9 shows the results of egg TVAR model with two thresholds. The threshold values are estimated to 1,477.827 kg and 166,029 kg, respectively. The farm and wholesale lag prices affect positively on farm price in regime 1. In regime 2 and regime 3, only the retail lag price is statistically significant for all prices. Especially, the impacts of retail lag price for farm and wholesale price are positive in regime 2, but the impact are negative in regime 3. This is interpreted that if diseases are less than a certain value, the retail lag price has a positive impact on the farm and wholesale price, but if diseases exceeds a certain value, then the retail lag price affects negatively on those prices.

Table 8. Results of TVAR model for broiler

	Farm price	wholesale price	Retail price
regime 1	Chicken disease ≤ 3,600kg		
Farm price(-1)	0.3939*** (0.1092)	0.6683*** (0.1982)	0.5396*** (0.1769)
wholesale price(-1)	0.1683*** (0.0635)	0.1455 (0.1153)	-0.2005* (0.1029)
Retail price(-1)	0.0214 (0.0331)	0.0750 (0.0600)	0.5821*** (0.0536)
c	331.8026** (156.0354)	1,073.6205*** (283.0912)	2,076.7793*** (252.6107)
regime 2	3,600kg < Chicken disease ≤ 8,016kg		
Farm price(-1)	-0.2768 (0.4750)	-0.4365 (0.8618)	-1.3009* (0.7690)
wholesale price(-1)	0.9214*** (0.3111)	1.2147** (0.5644)	2.7746*** (0.5037)
Retail price(-1)	0.0602 (0.1480)	0.1961 (0.2685)	-0.1302 (0.2396)
c	-1,135.9512 (725.6147)	-1,075.5395 (1316.4647)	-287.2280 (1174.7206)
regime 3	Chicken disease > 8,016kg		
Farm price(-1)	0.1139 (0.2581)	0.3324 (0.4683)	0.4306 (0.4179)
wholesale price(-1)	0.3384** (0.1506)	0.4246 (0.2732)	0.0222 (0.2438)
Retail price(-1)	0.0300 (0.0518)	-0.0074 (0.0940)	0.1367 (0.0838)
c	144.9590 (295.9303)	1,045.2015* (536.8990)	4,134.3461*** (479.0910)

a) ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

b) The blanket means standard error

Table 9. Results of TVAR model for egg

	Farm price	wholesale price	Retail price
regime 1	Laying hens disease ≤ 1,477.827kg		
Farm price(-1)	0.3210* (0.1679)	-0.0571 (0.1747)	0.1835 (0.1428)
wholesale price(-1)	0.2948* (0.1591)	0.6991*** (0.1656)	0.0475 (0.1353)
Retail price(-1)	0.0995 (0.0617)	0.0875 (0.0642)	0.4586*** (0.0525)
c	224.6358** (90.1065)	294.8388*** (93.7715)	740.6426*** (76.6522)
regime 2	1,477.827kg < Laying hens disease ≤166,029kg		
Farm price(-1)	-0.2299 (0.5372)	0.0039 (0.5591)	-0.1101 (0.4570)
wholesale price(-1)	0.2272 (0.4978)	0.0598 (0.5180)	0.0173 (0.4234)
Retail price(-1)	0.5150*** (0.1370)	0.5506*** (0.1426)	1.0373*** (0.1165)
c	234.6255 (326.2672)	213.2177 (339.5379)	12.0193 (277.5505)
regime 3	Laying hens disease >166,029kg		
Farm price(-1)	2.9033 (2.3866)	2.1611 (2.4837)	-1.6535 (2.0302)
wholesale price(-1)	-2.0155 (2.2095)	-1.2775 (2.2994)	1.5907 (1.8796)
Retail price(-1)	-0.2992* (0.1553)	-0.3223** (0.1616)	0.9871*** (0.1321)
c	1,000.1758*** (321.3083)	1,082.2568*** (334.3773)	-16.4937 (273.3320)

a) ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

b) The blanket means standard error

The results of the TVAR model are not able to clarify the direction of economic causality because TVAR model are based on just the relationship between the price and lag price variables. Therefore, we conducted a Granger causality test for the prices to identify the causality path. Then, we conducted the impulse response analysis based on the causality results.

Table 10. Results for Granger causality test

Null hypothesis	Pig	Broiler	Egg
farm not Granger cause wholesale	6.3785** (0.0120)	16.1942*** (0.0000)	0.0439 (0.8342)
wholesale not Granger cause farm	0.7533 (0.3860)	16.4302*** (0.0000)	2.5717 (0.1096)
retail not Granger cause farm	8.7966*** (0.0032)	4.0218** (0.0456)	20.0840*** (0.0000)
farm not Granger cause retail	84.4804*** (0.0000)	31.2380*** (0.0000)	5.2591** (0.0224)
retail not Granger cause wholesale	9.7953*** (0.0019)	10.9617*** (0.0010)	16.7934*** (0.0000)
wholesale not Granger cause retail	83.0654*** (0.0000)	23.4138*** (0.0000)	4.9334** (0.0270)

a) ***: $p < 0.01$, **: $p < 0.05$

The retail price has the Granger causality in both the farm and wholesale price. Also, the farm price has a significant effect on the wholesale price, but the wholesale price does not affect the farm price. All prices of broiler have two-way Granger causality. The price of egg has two-way Granger causality except between the farm and wholesale prices. Next, we performed the generalized impulse response analysis to see how all the variables in the TVAR model respond over time after shocks.

The results of the impulse response analysis of pig TVAR model in Figure 1 show that the response to each distribution stages is different according to the magnitude of infectious diseases for pig. In particular, the shock of the farm price on the wholesale price decline gradually in regime 1, but the shock increase until 8 weeks in regime 3. Moreover, the shock of the retail price on the wholesale price decrease rapidly until 6 weeks in regime 1, and then the impact is reversed. From these results, we found that the duration and speed of the shock are different depending on the magnitude of diseases. For example, the period when the shock is maximum, takes from 1 weeks to 3 weeks in regime 1 and takes 8 weeks in regime 3. The self-shock of the retail price seems to be more rigid in regime 3 than regime 1, in that the speed of shock is relatively slower regime 3 than regime 1.

The results of the impact responses of broiler TVAR model are summarized as follows. First, the impact response to all prices showed similar results in regime 2. The shock of the farm price on wholesale price has similar tendency in regime 1 and regime 3, but the shock of the farm price on the retail price is somewhat different in each regime. The shock of the retail price on the wholesale price decreases rapidly until 3 weeks in regime 1 and increases until 2 weeks in regime 3. This means that the duration and speed of the shock are different depending on the magnitude of diseases. Furthermore, we imply that pig prices are more inflexible than broiler prices because the shock of broiler prices seems to be disappeared more quickly than pig prices.

Figure 1. Impulse response results for pig prices

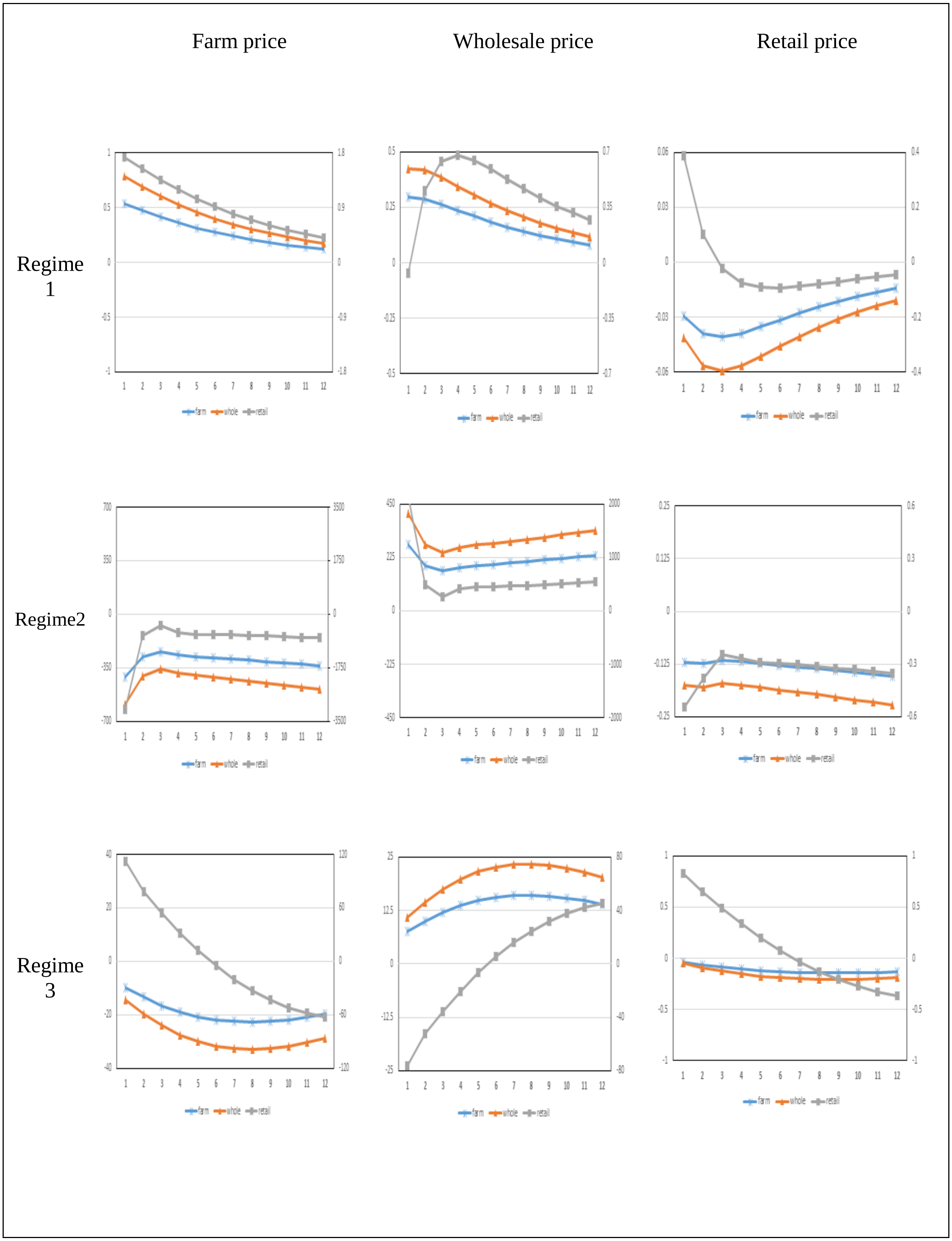


Figure 2. Impulse response results for broiler prices

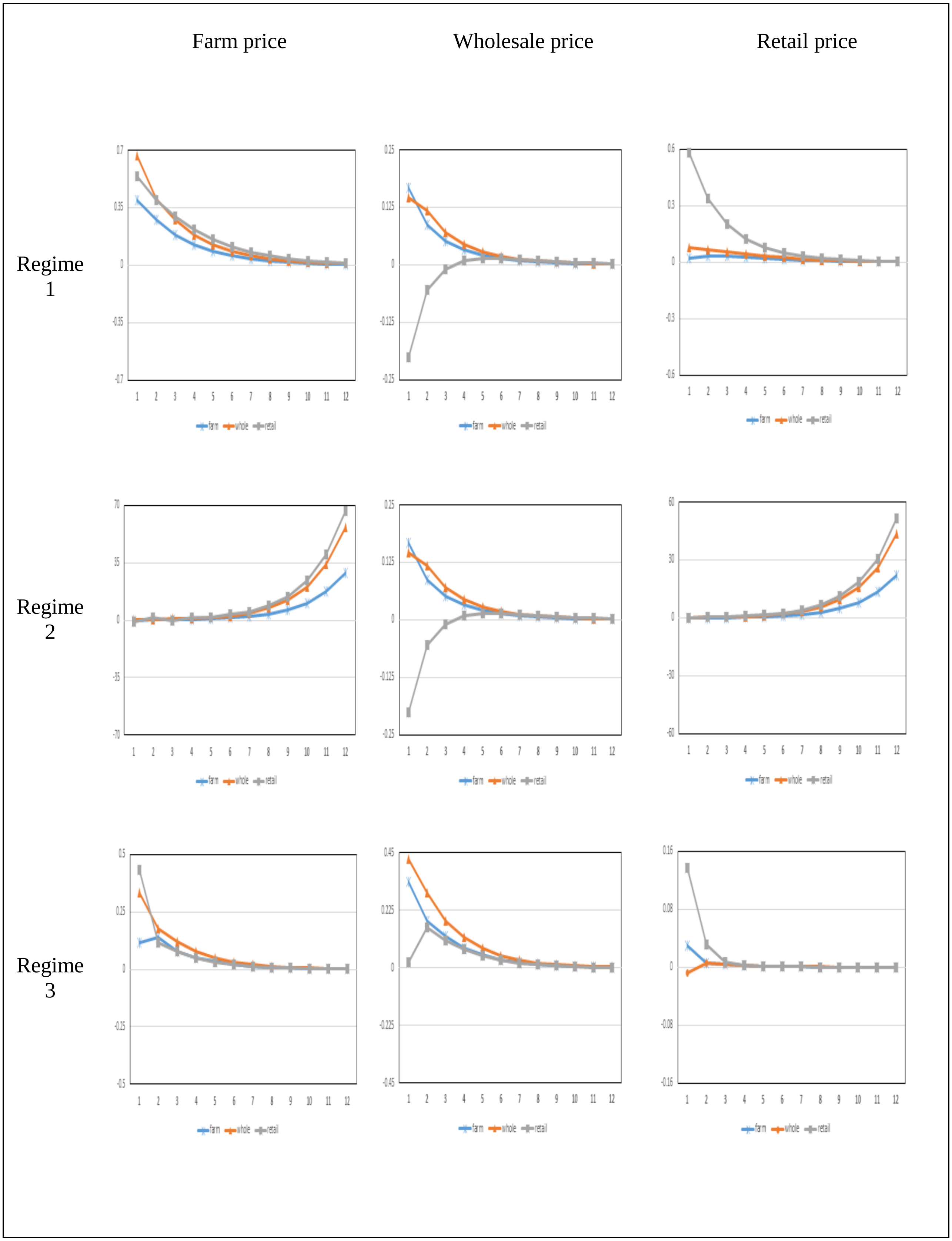
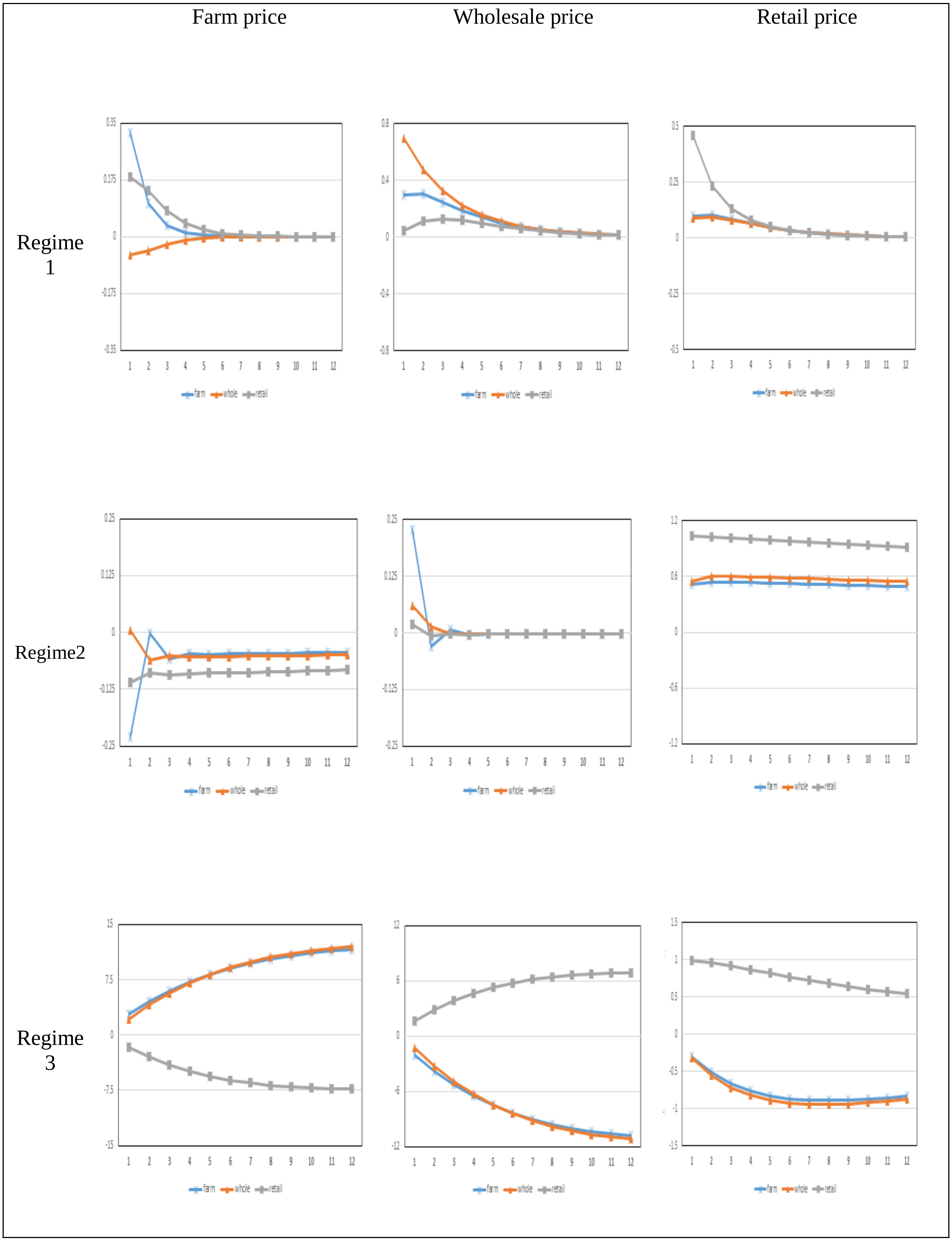


Figure 3. Impulse response results for the egg prices



The results of impulse response of egg TVAR model are as follows. The shock of all prices except the retail price increases gradually in regime 3. The shock of the farm price on the retail price remained constant in regime 1 and regime2 while the shock continues to increase in regime 3. The shock of the farm price on the retail price is highest in the order of 2 weeks, 3 weeks, and 8 weeks depending on regimes. Also, the shock of the retail price on the wholesale price is highest in the order of 3 weeks, 1 week, and 12 weeks depending on regimes. In other words, the shock stays longer in regime 3 than other regimes. This implies that impulse of egg price tends to be retained for a long period of time when incidence of diseases increases.

Conclusion

This study used the TVAR model and TVECM to determine whether the prices of pig, broiler, and egg have a nonlinear structure due to the incidence of livestock infectious diseases. Prior to the analysis, we conducted unit root test to ensure the stability of the data. The results showed that all prices of pig, broiler, and egg are nonstationary. Thereafter, threshold cointegration test is performed, which showed that there is no threshold cointegration in the prices of pig. Moreover, the prices of all livestock products have the threshold effect. The threshold values of the pig were estimated to 812.1278kg and 1,278.733kg. The threshold values of broiler were estimated to 3,600kg and 8,016kg, and threshold values of egg were estimated to 1,477.827kg and 166,029kg. Then, Granger causality was conducted to test the causality for the livestock products' price of different distribution stages, after then we analyzed the generalized impulse response function through causality path. As a result of analyzed the impulse response function, it was confirmed that the shock in each distribution stages is different according to the incidence of infectious diseases. The shock of the prices has different duration and speed according to the separated regimes by diseases.

This study has a distinction from the previous studies in that TVAR model, which has not been tried in previous studies, is used to analyze whether the price of livestock products has a nonlinear structure due to the infectious diseases. In addition, the results of threshold effect test show VAR model consisting of the prices of the livestock products is divided into 3 regimes according to the infectious diseases. This means that there exists the nonlinear structure in the livestock products' prices. Then, the generalized impulse response results show that when infectious diseases occurrence increases, the shock persisted for a longer period in pig and egg. Especially, the duration of shock is retained in order of egg, pig, and broiler in regime 3.

This suggests that if infectious diseases occur on a large-scale, government policies should be implemented to suit with each livestock products. For instance, in the case of broiler, the shock of prices tends to maintain about 3 to 6 weeks when diseases occur on a large-scale, so that it is necessary to implement short-term stabilization policy, such as the release of government' and private' stockpiles. In the case of pig, the shock of price lasts more than 12 weeks when a large-scale diseases occur. Therefore, it is necessary not only short-term policies such as securing supply through the import, but also long-term policies such as the supply and demand forecasting system to maintain the appropriate number of pig or the promotion for consumption of substitution goods through discount. Finally, in the case of egg, the shock of the price lasts more than about 12 weeks as with pig. Consequently, it is necessary to implement long-term policies such as restoring infrastructure for laying hens, along with short-term policies which increase supplies such as stockpile and imported egg.

In conclusion, the significant results of this study are expected to be useful resources for the price stabilization policy and distribution policy for livestock products. However, this study has the limitation in that it does not take into consideration the various economic factors related to the price of livestock products. It is also expected that more detailed interpretation will be made if economic analysis using specific numerical values such as variance decomposition analysis considering economic causality is added.

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