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The impacts of animal disease crises on the Korean meat market

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Abstract

Employing the error correction method and historical decomposition with direct acyclic graphs, we quantify the impacts of domestic and overseas animal disease crises on the Korean meat market. We have the following findings: (a) the market partially recovered 16 months after the domestic foot-and-mouth outbreak (FMD) in 2000, and 13 months after the domestic avian influenza (AI) incidents and the U.S. bovine spongiform encephalopathy (BSE) discovery in 2003; (b) animal disease outbreaks had differentiated impacts by disease type and at different levels of meat supply chain. Retail price margin increased relative to the farm and wholesale levels; and (c) disease outbreaks caused changes of dynamic interdependence between prices by meat type at different levels of meat supply chain.

JEL classification: C32, L11, Q11

Keywords: Animal disease outbreak; Error correction model; Direct acyclic graphs; Korean meat market; Historical decomposition; Price margins

1. Introduction

The adverse impacts of animal disease outbreaks reach beyond national borders as the food supply chain becomes increasingly global. Food scares or food safety risks emanating from foreign countries can be realized in domestic markets of importing countries. Shocks from localized animal disease outbreaks can be quickly transmitted to other regions and countries. For example, the bovine spongiform encephalopathy (BSE) discovery in the United Kingdom in 1996 caused disruptions in meat markets world wide (Kenneth et al., 2002).

This study investigates the impacts of animal disease outbreaks on the Korean meat market. Recently, the Korean meat market has been affected by three animal disease outbreaks: a foot and mouth disease (FMD) outbreak in Korea in April 2000, an avian influenza (AI) outbreak in Korea in December 2003, and the first BSE discovery in the United States in December 2003. BSE discoveries in Canada and the United Kingdom had less direct influence on Korean markets since Korea imports meat mainly from the United States. Korea banned beef imports from the United States immediately following the confirmation of the BSE on December 23, 2003, and it did not lift the import ban until July 2007, when boneless beef could again be imported from the United States to Korea.

We employ time series methods, mainly the error correction model (ECM) and historical decomposition of price innovations, accompanied by directed acyclic graphs (DAGs), to investigate in-depth the impacts of multiple disease outbreaks on prices of different meat types (beef, pork, chicken) at different levels of the marketing channel (retail, wholesale, and farm levels), price margin along the supply chain, and price interdependence in the system.

This study offers the following contributions to the literature. First, we consider multiple animal disease outbreaks of different disease types (AI, BSE, FMD) with different country of origin (domestic vs. international). Second, to our knowledge, this study is the first that simultaneously investigates the impacts of animal disease outbreaks on meat prices, the price margin along the supply chain, and price interdependence in the meat system. Accordingly, it provides a broader understanding of the impacts of disease outbreaks. Third, to our knowledge, there is no study that systematically investigates the Korean meat market. This study fills this gap and provides evidence from another country.

The remainder of this article is organized as follows. In the next section, we present a literature review of animal disease-related food scares. Section 3 presents the ECM and historical decompositions of price innovations. We provide an overview

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of the Korean meat market in Section 4. Section 5 discusses the data used in our study and presents empirical results. Conclusions are offered in the last section.

2. Literature review on animal disease related food scares

There is a rich literature investigating the impacts of animal disease outbreaks on meat demand. Burton and Young (1996) show that BSE has significantly negative impacts on the domestic beef demand using a dynamic almost ideal demand system (AIDS). Piggot and Marsh (2004) find a minimal impact of food safety information on meat demand. Major food scares induce large demand responses, but these responses are quickly dampened. Peterson and Chen (2005) find that, following the BSE discovery in Japan in September 2001, there was a structural change in the Japanese meat market followed by a two-month transition. McCluskey et al. (2005) find that the consumption of domestic and imported beef in Japan drastically dropped by 70% in November 2001, two months after the Japanese BSE discovery. Using a unique bar code (UPC)-level scanner data set, Schlenker and Villas-Boas (2007) find a pronounced and significant reduction in beef sales following the first BSE discovery in the United States, but the effect dissipates over the next three months.

A stream of literature focuses on the impact of animal disease outbreaks on meat prices. Lloyd et al. (2001) estimate that beef prices at the retail, wholesale, and producer levels in the United Kingdom fell by 1.7, 2.25, and 3.0 pence per kilogram, in the long-run, following the 1996 British government announcement of a possible link between BSE and its human version, variant Creutzfeldt-Jakob disease (vCJD). Pritchet et al. (2005) argue that the 2003 U.S. BSE discovery led to a 14% decrease in the choice boxed beef price and a 20% decrease in the fed cattle price between December 22, 2003, and January 8, 2004. Leeming and Turner (2004) find a negative effect of the BSE crisis on beef price but a positive effect on lamb price in the United Kingdom.

Following Gardner (1975), there is a broad literature on the price margin and factors that may influence price transmission. However, the literature on the effect of animal diseases on price transmission is relatively thin. Lloyd et al. (2006) and Sanjuan and Dawson (2003) find that the retail-to-farm price margin for beef increased following the U.K. BSE discovery in 1996. Similar increases were not found in the lamb and pork markets (Sanjuan and Dawson, 2003).

Other studies investigate the impact of food scares on futures prices in commodity markets and equity prices in stock markets. Henson and Mazzocchi (2002) find that the U.K. BSE discovery in 1996 had a negative impact on the equity prices of 24 companies in the United Kingdom. Schlenker and Villas-Boas (2007) find that cattle futures prices had a comparable drop relative to the estimated price using scanner data. Contracts with longer maturities had smaller price declines following the first U.S. BSE discovery.

This study will focus on the impact of animal disease outbreaks on meat prices, price margins, and the interdependence among prices in the Korean meat market.

3. Econometric model

To identify and quantify the impacts of animal disease outbreaks on the Korean meat market we employ time series methods, mainly the ECM, and historical decomposition of price innovations. The ECM allows us to compare the actual price that is affected by animal disease shocks and the forecasted price that uses only information before the animal disease outbreak occurs. The comparison will quantify the impacts on meat prices, as well as price margins, along the supply chain. However, due to substitution between different meat types and the supply chain integration, an animal disease outbreak will potentially affect meat consumption and meat prices at all levels within the supply chain. Historical decomposition of price innovations is employed to identify the dynamic interdependence within the meat price system and to quantify the contribution of each price series on the net change of a certain meat price following an animal disease outbreak.

3.1. Error correction model

We denote the number of price series of interest by n and the time period by t. Based on the Johansen's cointegrated vector autoregression (VAR) model with k lags (Johansen, 1988), the data generating process of X_t, where X_t is an $n \times 1$ vector of price series, can be modeled as an ECM with $k-1$ lags:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \, \Delta X_{t-i} + e_t, \tag{1}$$

where Δ is the first-order difference operator such that $\Delta X_t = X_t - X_{t-1}$, both Π and Γ_i are $n \times n$ parameter matrices, and e_t is an $n \times 1$ vector of price innovations that are not necessarily orthogonal. We also include 11 monthly dummies to account for seasonality along with a constant. There are different forms of deterministic terms in the ECM (Lütkepohl, 2005). We consider cases with or without linear trend. Equation (1) becomes

$$\Delta X_t = [\Pi, \mu] \begin{bmatrix} X_{t-1} \\ 1 \end{bmatrix} + \sum_{i=1}^{k-1} \Gamma_i \, \Delta X_{t-i} + e_t \quad \text{without linear trend,} \tag{2a}$$

and

$$\Delta X_t = [\Pi, \mu_1, \mu_2] \begin{bmatrix} X_{t-1} \\ 1 \\ t-1 \end{bmatrix} + \sum_{i=1}^{k-1} \Gamma_i \, \Delta X_{t-i} + e_t \quad \text{with linear trend,} \tag{2b}$$

where μ, μ_1, and μ_2 are $n \times 1$ parameter vectors.

There are different approaches to determine the optimal lag length of a VAR representation (k) and the rank of cointegration vectors (r). The conventional approach is a two-step procedure involving system-based likelihood ratio (LR) tests to determine r and k sequentially. This procedure is to determine the lag length using information matrices first; and then to determine the rank of cointergration vectors based on a trace test (Johansen, 1988) with test statistic given by

$$\text{trace} = -T \sum_{i=r+1}^{k} \ln(1-\lambda_i), \tag{3}$$

where T is the number of observations and λ_i's are ordered eigenvalues of matrix Π in Eqs. (2a) and (2b). This approach is popular due to its sound theoretical basis, computational simplicity, and superior performance relative to some other estimators (Brüggemann and Lütkepohl, 2005). However, this procedure might not be free from model specification problems that ultimately involve tradeoffs between model parsimony and fit, given the fact that the true model is rarely known (Wang and Bessler, 2005).

Recently, model selection methods based on information criteria have been proposed and implemented as an alternative to the conventional two-step procedure outlined above (Aznar and Salvador, 2002; Baltagi and Wang, 2007; and Phillips and McFarland, 1997). There are at least three advantages of the model selection method compared with system-based LR tests. First, it jointly estimates the cointegration rank and the optimal lag length in a VAR (Phillips, 1996). Second, the model selection method relieves researchers from the arbitrary choice of an appropriate significance level in contrast with formal hypothesis testing used in system-based LR tests. Third, Chao and Phillips (1999) and Wang and Bessler (2005) provide simulation evidence to show that the model selection methods based on information criterion give at least as good fit as system-based LR tests.

Geweke and Meese (1981) argue that Schwarz-loss criterion (SIC) loss may have a tendency to over-penalize additional regressors in contrast to other metrics. Hannan and Quinn (1979) suggest that Hannan and Quinn (HQ) loss performs better than SIC in large samples since HQ gives more consistent results. We use HQ information criterion to jointly determine the optimal lag length and the rank of cointegration vectors,

$$\text{HQ} = \ln(\det \hat{\Omega}_k) + k\left(\frac{2n\ln(\ln T)}{T}\right), \tag{4}$$

where $\hat{\Omega}_k$ is the maximum likelihood estimate of the variance–covariance matrix of Ω given lag length k and cointegration rank r, n is the number of variables, and T is the number of observations.

3.2. Historical decomposition

Historical decomposition is suitable for the investigation of atypical market events coming from the unanticipated exogenous (demand or supply) shocks such as the oil supply shocks (Kilian, 2008) or the 1987 U.S. stock market crash (Yang and Bessler, 2008). We employ historical decompositions to identify and quantify contributions of all the price series to the change of a certain price series due to animal disease outbreaks.

Historical decomposition is derived from the moving average representation of Eq. (1),

$$X_t = \sum_{i=0}^{\infty} \Theta_i \varepsilon_{t-i}. \tag{5}$$

The matrix Θ_0 summarizes the contemporaneous causal patterns between orthogonal innovations ε_t. Since e_t estimated from the ECM may exhibit off-orthogonal contemporaneous correlations, we need to convert e_t to orthogonal price innovations (ε_t), such that

$$\varepsilon_t = Ae_t. \tag{6}$$

The Choleski factorization, a widely used method, has a significant drawback as it allows researchers to arbitrarily choose one case among the various possible causal stories (Demirap and Hoover, 2003). This selection may not reflect "true" contemporaneous causal ordering among the variables.

Recently, several efforts have come forth using DAGs for contemporaneous identification in VAR-type models (Bessler and Lee, 2002; Swanson and Granger, 1997). DAGs uncover contemporaneous causal orderings based on the data itself, compared to the arbitrary ordering by the Choleski decomposition.

A DAG is a picture summarizing causal flows among variables. Arrows represent the direction of information flow between variables. No arrow or sequence of arrows is allowed to direct information flow from one variable back to itself. There are several algorithms discussed in the machine learning literature that can be used to identify and estimate the causal structure embedded in a set of VAR (or ECM) innovations. We use the greedy equivalent search (GES) algorithm. Details on the GES algorithm are given in Chickering (2002, pp. 520–524).

The GES algorithm employs a two-stage stepwise search according to the Bayesian Information Criterion approximation from Schwarz:

$$S(G,D) = \ln p(D \mid \hat{\theta}, G^k) - \frac{d}{2}\ln T, \tag{7}$$

where p is the probability distribution, $\hat{\theta}$ is the maximum-likelihood estimate of the unknown parameters, d is the number of free parameters of DAG G, T is the number of observations, and D is the data available to researchers. The scoring criterion considers the tradeoff between fit ($\ln p(D \mid \hat{\theta}, G^k)$) and parsimony modeled ($\frac{d}{2}\ln T$). The GES algorithm always moves in the direction that increases the Bayesian score the most.

The algorithm starts with an equivalence class corresponding to no dependencies among the variables (no edge between the variables) followed by a two-stage search procedure. The procedure consisting of (a) a forward equivalence search for the addition of single edges in the first stage where one equivalence class that has the highest score among all the possible equivalence classes is chosen for the next stage; and (b) a backward equivalence search for the deletion of single edges in the second stage where the equivalence class that leads to a local maximum is chosen. This procedure is repeated until there are no further additions or deletions of edges to improve the score.

Based on the orthoganized price innovations, the historical decomposition of the vector X at particular time $t = T_0 + k$ can be divided into two parts:

$$\underbrace{X_{T_0+k}}_{\text{actual price}} = \underbrace{\sum_{s=k}^{\infty} \Theta_s \varepsilon_{T_0+k-s}}_{\text{base projection}} + \underbrace{\sum_{s=0}^{k-1} \Theta_s \varepsilon_{T_0+k-s}}_{\text{difference}} . \quad (8)$$

The base projection utilizes information available up to time period T_0. The difference between the actual price and the base price projection is, thus, written as a linear function of innovations (new information) arising in each series between the period T_0 and period $T_0 + k$. Through the partition, historical decomposition allows us to examine the behavior of each price series in the neighborhood of historical events (animal disease outbreaks in our cases) and to infer how much each innovation contributes to the unexpected variation of X_{T_0+k}.

4. Korean meat market and animal disease outbreaks[1]

The Korean meat market has been continuously expanded. The total aggregate production value of the livestock industry is US$11.4 billion, which accounts for 33.5% of total production value in the Korean agricultural sector in 2005. The annual per capita meat consumption increased from 20 kg in 1990 to 32 kg in 2005, and average food calorie intake from meat increased from 3.7% in 1980 to 6.8% in 2004.

After the inception of the Uruguay Round Agreement on Agriculture, Korea has become one of the major players in international trade. As of 2003, Korea is the ninth largest meat importing country and the fourth largest beef importing country in the world. In particular, among all the countries that import meat products from the United States, Korea is the second largest for beef (US$816 million), the fourth largest for pork (US$79 million), and the sixth largest for poultry (US$50 million) (Henneberry and Hwang, 2007).

Korea significantly relies on imports to meet its increasing meat demand. The total imported beef doubled and its self-sufficiency decreased from 53.5% to 36.3% from 1996 to 2003. Pork consumption constitutes more than half of the meat consumption. The leading pork exporting countries to Korea are the United States, Chile, Canada, and Belgium. Historically, pork has been highly self-sufficient with a sufficiency rate of 80% in 2005. Chicken consumption has been increasing with the growing interest in consuming white meat. Korea mainly imports chicken from Denmark, the United States, and China.

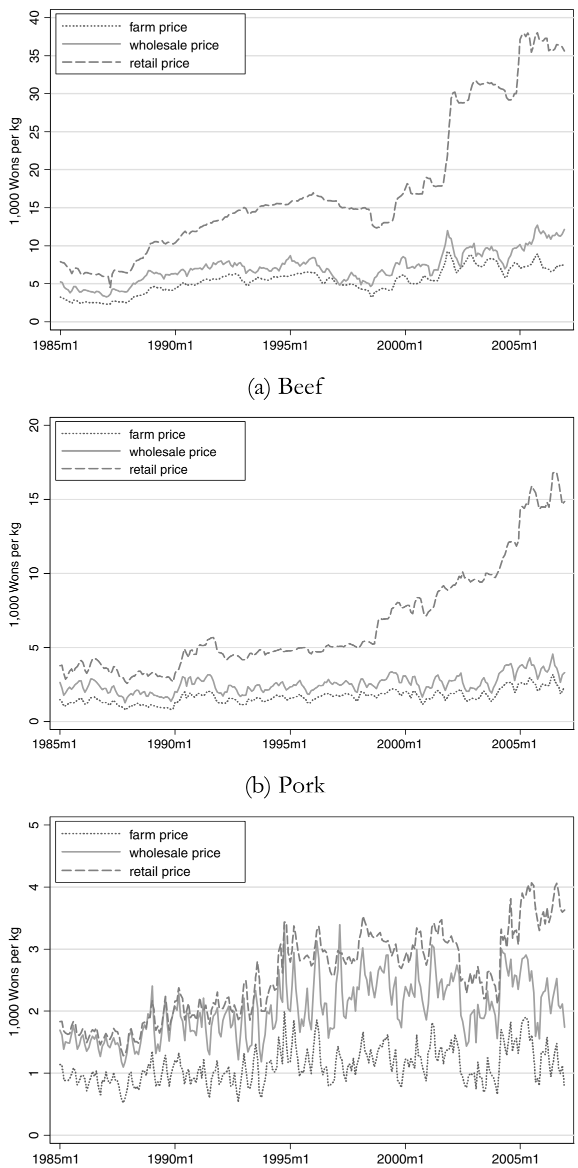
Due to the growing consumer concern about food safety and quality, the Korean government implemented a mandatory "Hazard Analysis and Critical Control Points" (HACCP) program in the meat supply chain in 1997. "Country of Origin" has been brought into the Korea market since 1999. Meanwhile, domestic meat producers and retailers have adopted various market strategies, such as product certificate programs and branding to differentiate their product and to meet the demands of certain consumer segments.

Since Korea exhibits significant import dependence, it is exposed to risk from animal disease outbreaks in exporting countries, in addition to domestic incidents. Several animal disease outbreaks that have occurred both within and outside of Korea have caused significant disruptions in the meat market since 2000. The largest outbreak case of FMD in Korea was confirmed on March 25, 2000, from an infected dairy cow farm in Paju county, Kyonggi province. Fourteen more FMD infected cases in Chungnam and Chungbuk provinces were reported on a dairy farm and a domestic high quality cattle (Hanwoo) farm in April 2000. Movement of all animals and animal related products within a 20 km radius of the outbreak farms were restricted to avoid further spread of FMD. As a result, a total of 2,216 head of livestock (cows, hogs, and lambs) were slaughtered by the end of April 2000. Japan imposed an import ban on pork from Korea.

The first AI case was reported on a Korean native chicken farm in Umsong county, Chungbuk province on December 10, 2003, followed by 18 additional cases diagnosed nationwide. As a result of the AI incidents, 5,283,493 head of poultry (mainly chickens) were slaughtered along with vaccination and movement restriction of animals and humans in the affected zones. Chicken consumption fell by 30% after the AI incidents.

In contrast with the AI and FMD outbreaks, BSE has not been discovered in Korea. However, the United States is the largest country exporting beef to Korea. In 2003, beef imported from the United States accounted for 68% of the total beef imported and 44% of the total beef consumption in Korea. Following the U.S. BSE discovery in December 2003, Korea banned imports of beef and offals from the United States. Australia became the largest beef exporting country with its exports accounting for over 75% of U.S. beef imports since 2004. The overall beef consumption in Korea dropped by 16%, and the consumption of imported beef fell by 27% in 2004. In contrast, the consumption of domestically produced beef has had little change and, rather, a slight increase in the same period. Meanwhile, pork imports had a substantial increase of 185% from 2003 to 2005, which suggests a significant substitution effect.

[1] Figures mentioned in this section are from internal reports by the Ministry of Agricultural and Forest of Korea except that cited from literature.



(a) Beef

(b) Pork

(c) Chicken

Fig. 1. Monthly prices of beef, pork, and chicken at the farm, wholesale, and retail levels (January 1985–December 2006).

5. Data and empirical results

The data used in this study are monthly Korean meat prices of beef, pork, and chicken at the retail, wholesale, and farm levels from January 1985 to December 2006. All series are provided by Korea Agro-Fisheries Trade Corporation (KAFTC). Fig. 1 plots these nine monthly price series. The retail prices of beef and pork have a clear upward trend since 1999, while the prices at the wholesale and farm levels are relatively stable.

We first test for nonstationarity of each price series using Dickey Fuller (DF) tests and Augmented Dickey Fuller (ADF) tests. The results in Table 1 suggest that all the price series, except the chicken prices at the farm and wholesale level (FC and WC) and the wholesale pork price (WP), are nonstationary at the 5% significance level. However, the first-order difference of each price series is stationary.

Table 1
Tests for nonstationarity of monthly meat price series

Meat price series	Dickey Fuller Test		Augmented Dickey Fuller Test	
	Level	Difference	Level	Difference
Beef				
Farm	−1.31	−9.06**	−2.36 (1)	−9.96 (5)**
Wholesale	−1.38	−14.29**	−1.38 (1)	−10.59 (1)**
Retail	0.75	−9.23**	−0.29 (1)	−9.13 (1)**
Pork				
Farm	−2.65	−11.92**	−2.70 (2)	−13.86 (1)**
Wholesale	−3.47*	−13.26**	−3.34 (2)*	−14.02 (1)**
Retail	1.14	−11.37**	0.90 (2)	−11.80 (1)**
Chicken				
Farm	−6.58**	−16.84**	−6.73 (1)**	−13.07 (2)**
Wholesale	−5.74**	−16.82**	−5.83 (1)**	−12.71 (3)**
Retail	−2.17	−15.80**	−1.73 (2)	−14.59 (1)**

The asterisks, * and **, indicate 5% and 1% significance levels, respectively. The critical value is −2.89 at the 5% significance level and −3.51 at the 1% level. Schwarz information criterion, SIC $= \ln(\det \hat{\Omega}_k) + k(\ln T/T)$, is applied to determine the number of lags that is listed in parentheses when we conduct ADF tests, where $\hat{\Omega}_k$ is the maximum likelihood estimate of variance–covariance matrix, T is the sample size, and k is the lag length.

The optimal lag length and the rank of cointegration vectors are the same when determined sequentially or jointly, which is consistent with Wang and Bessler's finding (2005). Table 2 summarizes the results on the optimal lag length (k) and the cointegration rank. SIC, HQ, and Hatemin-J metrics suggest a levels VAR with two lags, while AIC metrics suggests three lags. Since the optimal lag length determined by HQ metrics, through the parsimony principle, is two and further since SIC may have tendency to over-penalize additional regressors in contrast to other metrics (Geweke and Meese, 1981), we conclude a levels VAR with two lags. The trace test results show that we reject the null hypotheses of $r = 0$, $r \leq 1$, and $r \leq 2$ and fail to reject the null hypothesis of $r \leq 3$ at the 5% significance level for both specifications (with or without linear trend). Hence, we conclude that $r = 3$. Alternatively, following the model selection method we conclude that the optimal lag length is two with three cointegrating vectors, since this combination gives the lowest HQ loss metric (see Fig. 2).

5.1. The impacts of animal disease outbreaks on the Korean meat prices

We first estimate an ECM using the information from January 1985 to March 2000, a month prior to the domestic FMD outbreak and then conduct out-of-sample forecasting of meat

Table 2
Determining the optimal lag length and the cointegration rank sequentially

Optimal lag length of a level VAR

Lag	Schwarz information criterion (SIC)	Akaike information criterion (AIC)	Hannan and Quinn (HQ)	Hacker and Hatemin-J (HJ)
0	111.30	111.10	111.22	111.25
1	95.57	93.67	94.90	95.20
2	**95.40**	92.76	**94.12**	**94.69**
3	96.52	**92.14**	94.62	95.47
4	97.77	92.65	95.26	96.39
5	99.07	93.19	95.94	97.35
6	100.26	92.61	96.52	98.20

Trace tests for ECM under two specifications of deterministic term

Rank	Without linear trend		With linear trend	
	Trace statistics	Critical value (5%)	Trace statistics	Critical value (5%)
$r = 0$	297.54	208.27	287.50	197.22
$r = 1$	212.27	169.41	204.63	159.32
$r = 2$	139.09	134.54	131.65	125.42
$r = 3$	89.08*	103.68	82.27*	95.51

Information criteria metrics used to identify the optimal lag length (k) of a level VAR are $\text{SIC} = \ln(\det \hat{\Omega}_k) + k(n \ln T/T)$; $\text{AIC} = \ln(\det \hat{\Omega}_k) + k(2n/T)$; $\text{HQ} = \ln(\det \hat{\Omega}_k) + k(2n \ln(\ln T)/T)$; and $\text{HJ} = \ln(\det \hat{\Omega}_k) + k(n \ln T + 2n \ln \times (\ln T)/T)$; where $\hat{\Omega}_k$ is the maximum likelihood estimate of variance–covariance matrix, k is the proposed lag length, n is the number of variables, and T is the sample size. Bold indicates the minimum value of the loss metric. Figures with asterisks(*) indicate that corresponding null hypothesis cannot be rejected at the 5% significance level.

prices of 44 months after the event but before the next animal disease outbreak occurred, i.e., from April 2000 to November 2003.[2,3]

We use the same procedure to conduct forecasting of meat prices of 36 months after the domestic AI incidents and the U.S. BSE discovery in December 2003, i.e., from January 2004 to December 2006. We denote by x_{ij}^d and F_{ij}^d the actual and forecasted prices, where i indicates meat type, j indicates the farm ($j = f$), wholesale ($j = w$), and retail ($j = r$) levels, and d indicates disease type, either the 2000 FMD outbreak (d = FMD) or the 2003 AI/BSE incidents (d = AB). The percent change of the actual price relative to the forecasted price is

$$\Delta P_{ij}^d = \frac{x_{ij}^d - F_{ij}^d}{F_{ij}^d} \times 100. \quad (9)$$

[2] Using time varying cointegration approach we forecast prices using data before and after the indicated break-point in 2000. The forecasts do not fully support such break.

[3] Forecasting can be conducted either in-sample using the entire sample or out-of-sample obtained from a sequence of recursive or rolling regressions. In general out-of-sample forecasting has a better performance than in-sample forecasting, the latter being biased in favor of detecting spurious predictability (Ashley et al., 1980).

5.1.1. The impacts of the domestic FMD outbreak on the meat prices

Fig. 3 illustrates $\Delta P_{ij}^{\text{FMD}}$ over time for beef, pork, and chicken along the supply chain following the 2000 FMD outbreak. Figs. 3a and 3b suggest that the FMD outbreak had negative effects on the beef and pork markets. The beef and pork prices decreased in the short run. The retail price rebounded earlier than the farm and wholesale prices. The magnitude and timing of the changes were different between the beef and pork markets. The price decreases in the first seven months after the event were more dramatic in the pork market than in the beef market (up to 40% for the pork price and 13% for the beef price at the farm level, with the corresponding numbers at 38% and 4% at the wholesale level). The retail beef price recovered eight months after the event, but the price recovery at the farm and wholesale levels was almost six months behind. Overall, the beef market appeared to have recovered 16 months after the event. Fig. 3b suggests that the 2000 FMD outbreak had long-term adverse impacts on the farm and wholesale pork prices—prices did not recover for 44 months after the outbreak. The long-run impacts on the farm and wholesale prices may be due to the disruption of the production cycles.

In contrast to beef and pork prices, chicken appeared to have benefited from the outbreak. Its prices increased up to 34% at the farm and wholesale levels and up to 10% at the retail level between the second and eighth months following the FMD outbreak. However, the substitution was not permanent, since the chicken prices fell after the beef and pork markets recovered.

5.1.2. The impacts of the AI/BSE incidents in December 2003 on meat prices

Fig. 4 illustrates the percentage change of price, $\Delta P_{ij}^{\text{AB}}$, for beef, pork, and chicken along the supply chain following the 2003 Korean AI and the U.S. BSE events.

Immediately after the U.S. BSE discovery, Korea banned beef imports from the United States, which caused the total imported beef to drop by 71% in January 2004 compared to the previous year. The import ban may have led to a demand increase for domestically produced beef and therefore may result in a price increase of domestic beef. On the other hand, consumers may have been reluctant to consume beef, since they may have not felt secure about beef regardless of whether it was imported or domestic. As of January 2004, the consumption of domestic beef fell by 37.2%, and retail beef price dropped by 4.7% over the previous year. As shown in Fig. 4a, the retail beef price decreased by 10% in the 10th month, which suggests the impact on the demand side dominates. The concern over the safety of beef consumption among consumers might be one of the main factors that caused a substantial decrease in prices of domestically produced beef, even though the BSE discovery did not occur in Korea. However, the retail beef price rebounded and recovered 13 months after the incidents. Fig. 4a also shows an immediate, sharp price drop at the farm and wholesale levels following the animal disease

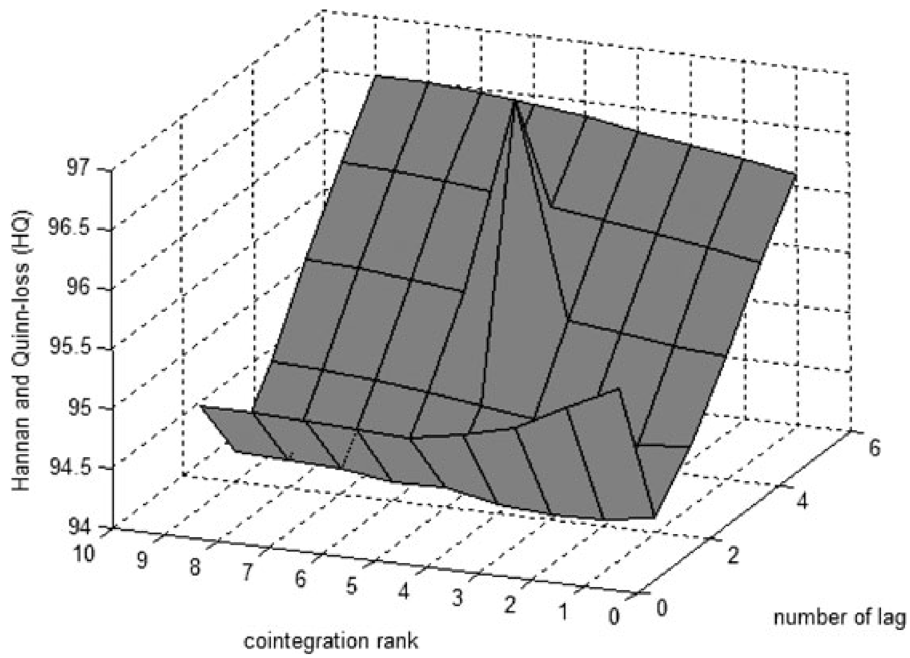


Fig. 2. Hannan and Quinn (HQ) loss given different combinations of cointegration ranks (r) and lag length (k).

incidents. The farm and wholesale beef prices decreased by 28% in the sixth month after the incidents and the wholesale beef rebounded and eventually recovered 14 months after the incidents. But, the farm beef price did not fully recover even three years after the incident.

Fig. 4c shows that chicken prices rebounded quickly following a substantial immediate price fall after the incidents. The fast recovery of chicken prices from the AI shock may be attributed to the promotional campaign of chicken consumption and reopened trade of heated chicken meat products in July 2004, as well as the substitution of chicken for beef due to the U.S. BSE discovery. Fig. 4b clearly shows that the pork market gained from the incidents as the prices of pork increased.

5.1.3. Differentiate impacts between two incidents in 2000 and 2003

Both FMD and BSE directly affect the Korean beef market, as cattle are vulnerable to both diseases. Comparing Figs. 3 and 4, we note that the impact of the BSE outbreak that occurred in the overseas market was greater than that of the domestic FMD outbreak. First, the initial beef price drop at three supply chain tiers within the first six months was much larger following the BSE discovery than the FMD outbreak. Second, the price recovery came earlier in the BSE case (13 months after the event for the BSE case and 16 months for the FMD case). The farm beef price did not recover to the pre-event level after the BSE event.

FMD directly affects the pork market. Pork prices decreased and the farm and wholesale pork prices did not recover three years after the event. The presence of the long-term adverse impact of the 2003 FMD outbreak at the farm and wholesale level may be related to the disruptions to animal production cycles caused by mass slaughter. However, the BSE incident affected the pork market through consumption substitution, and pork prices increased following the 2003 BSE and AI incidents.

5.2. The impacts of animal disease outbreaks on price margins

The question addressed here is whether and by how much animal disease outbreaks increase or decrease the price margin along the supply chain. For example, the retail-to-farm price margin $\mathrm{PM}^d_{i,rf}$ that is affected by animal disease outbreak d is $x^d_{ir} - x^d_{if}$, but it is $F^d_{ir} - F^d_{if}$ if there is no disease outbreak. The changes in the price margins along the supply chain due to animal disease outbreak d are

$$\mathrm{PM}^d_{i,rf} = \left(x^d_{ir} - x^d_{if}\right) - \left(F^d_{ir} - F^d_{if}\right) \quad \text{retail-to-farm,} \tag{10a}$$

$$\mathrm{PM}^d_{i,wf} = \left(x^d_{iw} - x^d_{if}\right) - \left(F^d_{iw} - F^d_{if}\right) \quad \text{wholesale-to-farm,} \tag{10b}$$

$$\mathrm{PM}^d_{i,rw} = \left(x^d_{ir} - x^d_{iw}\right) - \left(F^d_{ir} - F^d_{iw}\right) \quad \text{retail-to-wholesale.} \tag{10c}$$

A disease outbreak widens the price margin at level l relative to level m if $\mathrm{PM}^d_{i,lm} > 0$, narrows the price margin if $\mathrm{PM}^d_{i,lm} < 0$, or has no effect on the price margin if $\mathrm{PM}^d_{i,lm} = 0$.

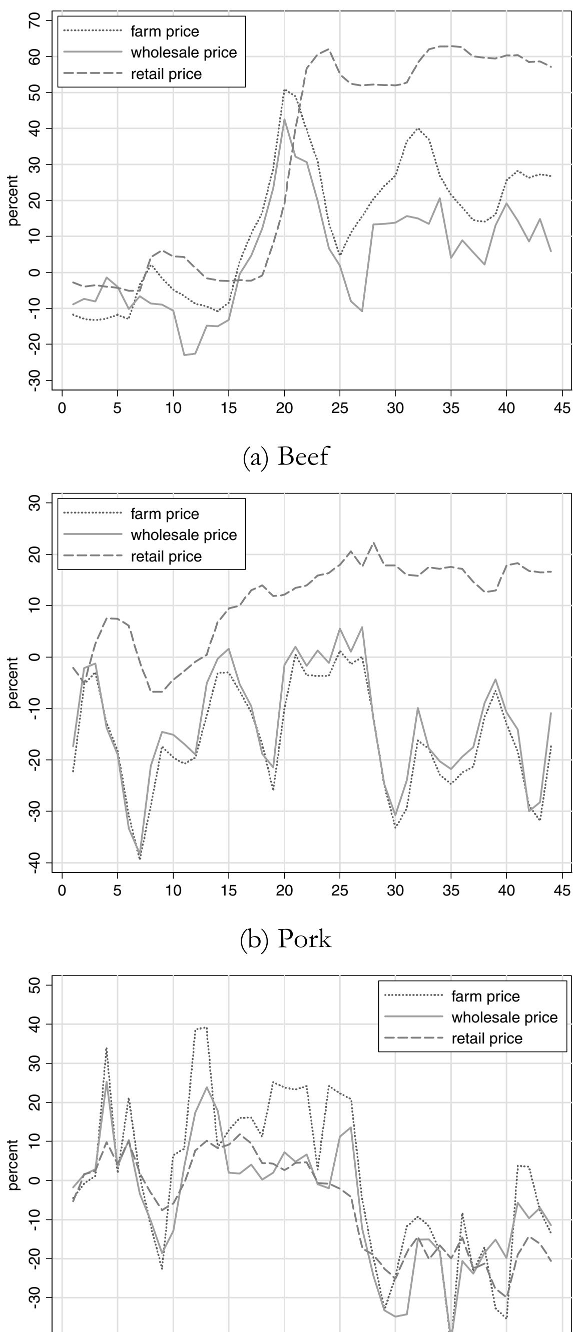


Fig. 3. Percentage change of the actual price relative to the forecasted price following the FMD outbreak in April 2000 and before the AI/BSE incidents in December 2003 (the *x*-axis is the number of months after the 2000 FMD outbreak).

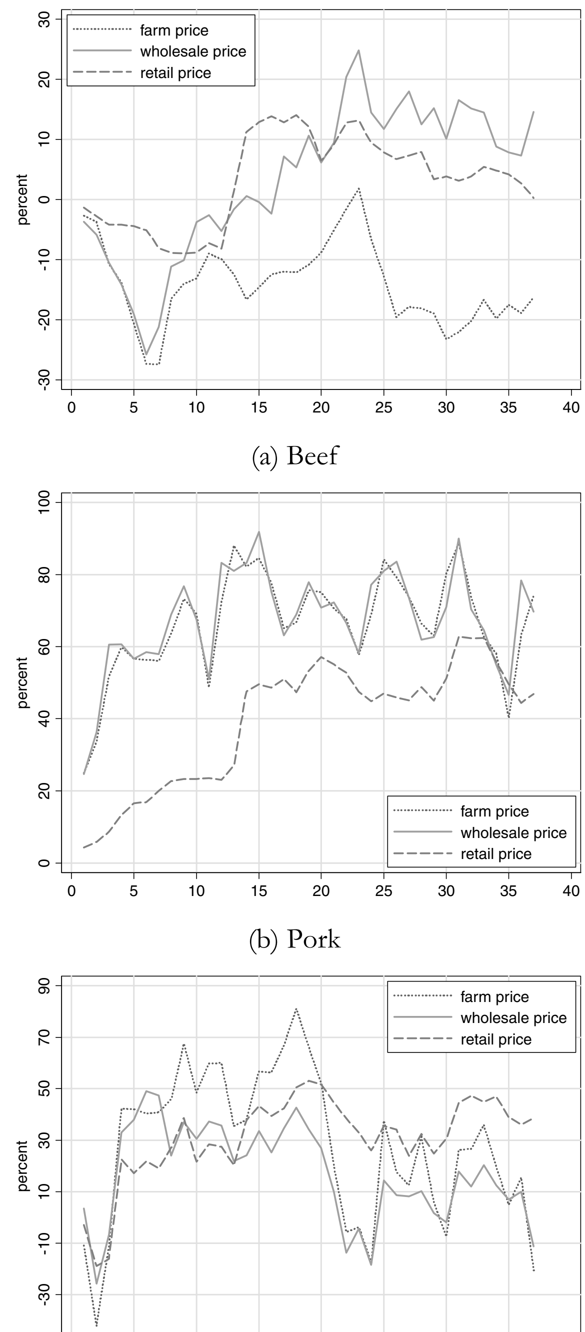
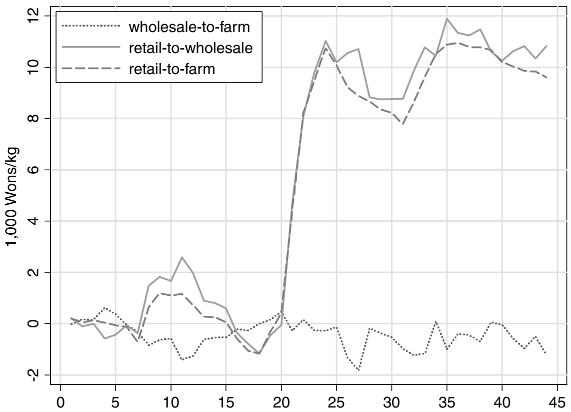


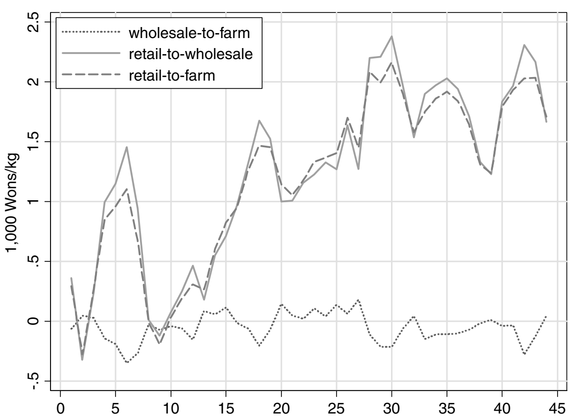
Fig. 4. Percentage change of the actual price relative to the forecasted price following the AI/BSE incidents in December 2003 (the *x*-axis is the number of months after the incidents).

5.2.1. The impacts of the 2000 FMD outbreak on the price margins

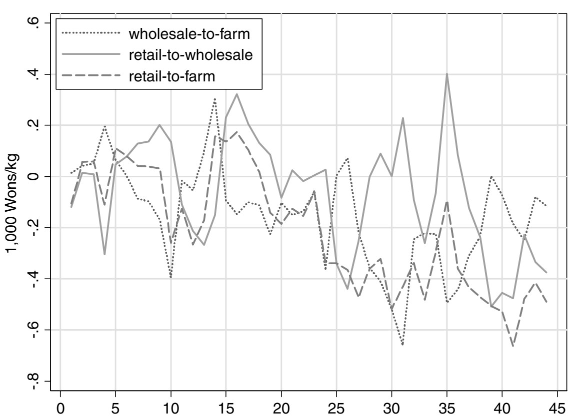
Fig. 5 shows changes in the price margins resulting from the 2000 FMD outbreak. The results suggest that the price margins along the supply chain stayed almost constant for six months after the FMD outbreak for beef and three months for pork. After this period, the price margin at the retail level, relative to the farm and wholesale levels, started to increase.



(a) Beef



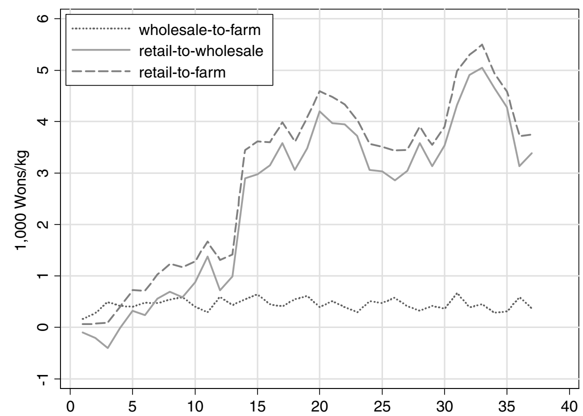
(b) Pork



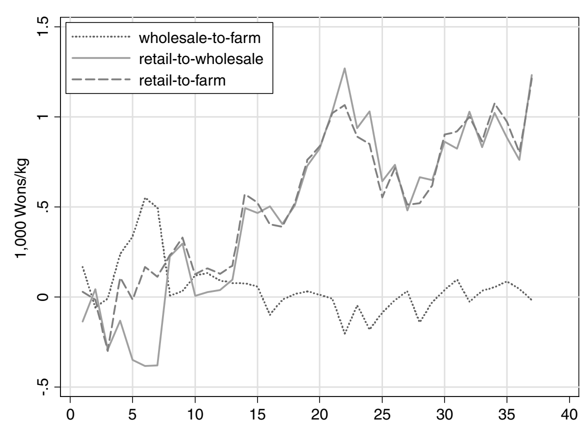
(c) Chicken

Fig. 5. Changes in the price margin along the supply chain following the FMD outbreak in April 2000 and before the BSE/AI incidents in December 2003 (the *x*-axis is the number of month after the event).

(a) Beef



(b) Pork



(c) Chicken

Fig. 6. Change in the price margin along the supply chain following the AI/BS incidents in December 2003 (the *x*-axis is the number of months after the incidents).

Fig. 6 shows changes in the price margins resulting from the 2003 AI/BSE incidents. In the pork market, the price margin at the retail level relative to the farm and wholesale levels increased, while there was almost no change between the wholesale and farm levels as consumers may substitute beef and chicken for pork. In the beef market the price margin at the retail level relative to the farm or wholesale level stayed almost the same in the first four months, decreased between month five and twelve, and finally increased starting from the thirteenth month after the animal disease incidents (at which the beef prices started to rebound). In the poultry meat market, despite the initial decrease the retail price margins relative to the farm and wholesale levels increased starting from the fourth month after the animal disease incidents.

The finding that the retail price margins relative to the farm and wholesale level increased suggests that retailers may actually gain from the disease outbreak, which is consistent with Lloyd et al. (2006) and Sanjuan and Dawson (2003). As discussed by Lloyd et al. (2006), the fact that retailers may gain from disease outbreaks may be attributed to the market power at the retail level. According to the Korean Statistical Information Service (KOSIS), there are approximately 250 stores in Korea that have 100 or more employees. These stores are owned by only five companies (Shinsegae E-mart, Lotte mart, Carrefour, Samsung Home-Plus, Wal-Mart).[4] Sales of these stores account for approximately one-third of total sales in the retail market. Indeed, the retail market, in general, is highly concentrated in Korea. These retailers may use their market power to gain from the disease outbreaks.

5.2.2. The impacts of the 2003 AI/BSE incidents on the price margins

Following the AI/BSE incidents consumers may have substituted pork for beef and chicken. Hence, the price margin at the retail level relative to the farm and wholesale levels may have increased while there may have been little change between the wholesale and retail levels in the pork market. In the beef market the incidents did not change the price margin at the retail level relative to the farm or wholesale level in the first four months after the animal disease incidents. The price margin first decreased, and then increased starting from the thirteenth month after the incidents (when the beef prices started to rebound).

5.3. The impacts of animal disease outbreaks on dynamic price interdependence

Our analysis so far did not address possible changes in interdependence among price due to disease outbreaks. We employ historical decomposition to evaluate how much each price innovation accounts for the atypical variation of a certain price due to animal disease shocks.

Using the correlation matrix of price innovations estimated from the ECM, we employ TETRAD IV with the GES algorithm to identify the contemporaneous causal flows between price innovations. The results in Fig. 7 suggest the innovations in the farm prices directly affected the wholesale prices in three meat markets. The innovation of the farm chicken price also directly affected its price at the retail level. The retail pork price played an important role in the pork market, since it directly or indirectly affected the farm and wholesale pork prices. The beef price at the farm and wholesale levels did not directly affect the retail beef price, but affected the retail price through the price series of pork and chicken.

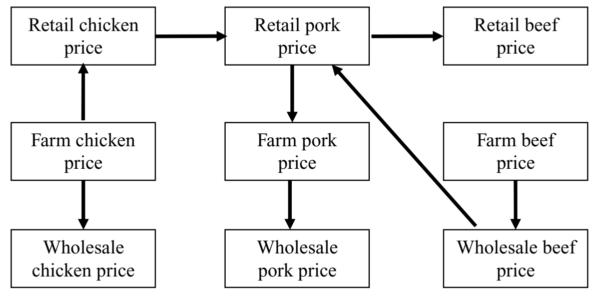


Fig. 7. Contemporaneous causalities based on DAG results using the GES algorithm.

Historical decomposition of each series is implemented over 23 months: two months before each event, the month the incident occurred, and 20 months following the event. The bar chart in Fig. 8 illustrates the contribution of each price series, either negative or positive, to the abnormal change in the retail beef price responding to either the 2000 FMD outbreak or the 2003 AI/BSE incidents.[5] The deviation of the actual meat price relative to the base projection, which is represented by the solid line, shows that the 2003 AI/BSE incidents had greater impacts on the retail beef price than the 2000 FMD outbreak in terms of larger price decrease and longer recovery duration. Fig. 8a shows that in the first six months after the event, the farm beef price innovation explained the majority of the retail beef price innovation. However, after six months, the contribution of farm beef price diminishes and is replaced by the contributions from the retail beef, retail pork, and farm chicken prices. This may reflect the supply shock as the Korean government slaughtered infected cattle immediately after the event. Fig. 8b shows that the farm beef price innovation had a strong negative contribution to the retail beef price innovation, followed by the wholesale chicken price following the 2003 AI/BSE incidents.

The basic message of Fig. 8 is that the significance of the contribution from each price innovation changed over time following the disease outbreak, which may suggest that the interdependence structure within the meat system changed as well.

We also have the following findings based on the historical decomposition of other price innovations. First, the variation of the farm price was mainly due to the shocks of its own price under both animal disease outbreaks. Second, in the case of the AI/BSE incidents, price variation at the wholesale level was mainly attributed to the innovation of the farm price, and its own contribution was relatively small. In the case of the 2000 FMD outbreak, the wholesale pork price almost solely contributed to its upward movement. Third, farm prices played a dominant role in explaining the variation of the retail prices in both outbreaks, except for the retail beef and pork prices after the 2000 FMD outbreak.

[4] As of May 2005, Wal-Mart phased out of the Korean market.

[5] Historical decomposition figures for other variables are available upon request.

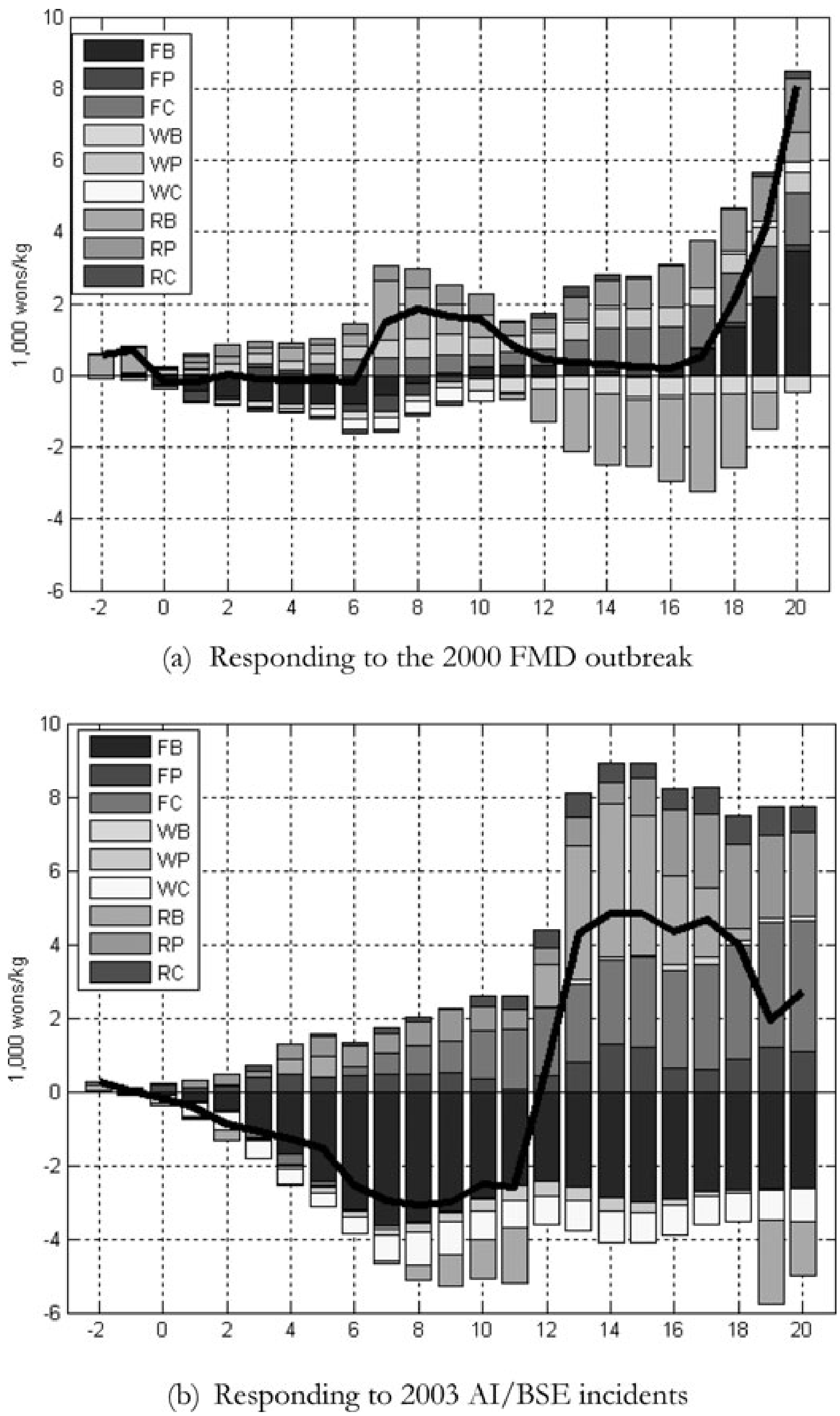


Fig. 8. Contribution of each price series on the innovation of retail beef price when responding to the animal disease outbreaks. (Each stacked bar illustrates positive or negative contribution of nine price series to the innovation of retail beef price. The solid line represents the deviation of the actual retail beef price from the base projection. The *x*-axis is the number of months before the event and after the event while the event occurred in month zero.) This figure appears in color in the on-line version of this article.

6. Conclusion and future research

Employing time series methods, mainly the ECM and historical decomposition of price innovation, accompanied by DAGs, we identify and quantify the impacts of domestic (FMD and AI) or overseas (BSE) animal disease crises on the Korean meat supply chain.

We find that animal disease outbreaks caused a temporary price shock to the Korean meat market, regardless of whether it was overseas or domestic and regardless of disease type (FMD, AI, or BSE). However, the market rebounded and eventually partly or fully recovered. The adverse impacts of the 2000 FMD outbreak dissipated and then partly recovered over the next 16 months, and over the next 13 months for the AI/BSE incidents. Exceptions are that the wholesale and farm pork prices in the case of the 2000 FMD outbreak, and the farm beef price in the case of the 2003 AI/BSE incidents, stayed lower than the pre-event level for more than three years, which may be attributed to the supply disruptions. Furthermore, the AI/BSE incidents led to more significant changes in beef prices in the first six months compared with the FMD outbreak. The pork market gained from the AI/BSE incidents due to consumption substitution, but the gain was short-lived.

We find that the retail price recovered ahead of other prices and the retail price margin relative to the wholesale and farm levels became wider despite the initial price drop at the retail level. Given the concentrated retail market in Korea, these results imply that exogenous shocks like animal disease outbreaks can influence the price margin along the supply chain. This result appears to be consistent with the market power argument suggested by Lloyd et al. (2006). In addition, we discover that the wholesale-to-farm price margin was relatively stable. Therefore, the analysis of price margin indicates that both animal disease outbreaks triggered asymmetric price transmission in the Korean meat supply chain.

We identify the interdependence among the price series and its change when facing animal disease outbreaks using historical decomposition of price innovations. The results suggest that the farm level price innovation has played a major role in explaining the innovations of the wholesale and retail prices in each market. Immediately following the disease outbreaks, there was a shortage in the beef supply in the Korean beef market either because the Korean government slaughtered infected cattle after the FMD outbreak or banned the imports from the United States after the BSE discovery. This fact may explain the finding that the retail beef price innovation was explained mainly by the farm level beef price in the first few months after the event. But the contribution of the farm beef price dissipated and eventually was dominated by contributions from other price series in the long term.

This study makes several contributions to the literature on the impact of animal disease outbreaks. First, we consider multiple animal disease outbreaks of different disease types (AI, BSE, FMD) with different countries of origin (domestic vs. overseas). Second, to our knowledge, this study is the first that simultaneously investigates the impacts of animal disease outbreaks on meat prices, price margins along the supply chain, and price interdependence in the meat system. It provides a broader understanding of the impacts of disease outbreaks. Third, the majority of literature that investigates impacts of animal disease outbreaks on meat markets focuses on markets in the United States, Canada, Europe, or Japan. To our knowledge this study is the first that systematically investigates the Korean meat market.

We only considered domestic prices in the meat supply chain because of the lack of data on imported meat price. Hence, the currently available data does not allow us to explain the role of imported meat price in the Korean market or investigate the relationship between imported meat price and the domestic meat prices. Also, animal disease outbreaks cause supply disruptions, such as, for example, mass slaughter of cattle in the event of an FMD outbreak. However, we do not have quantity data, which eliminates the possibility to directly incorporate the impact of the supply shock in the meat demand system. A larger system, including imported meat prices as well as quantity along the supply chain, should be analyzed to have a more complete understanding of the impacts of animal disease outbreaks, which can be a direction for future research.

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