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 oversea animal disease crises on the Korean meat markets. We find that (a) the market partially recovered 16 months after the foot-and-mouth outbreak in 2000, and 13 months after the avian influenza and the U.S. BSE incidents in 2003; (b) animal disease outbreaks have differentiate impacts by disease type and supply chain level. Retailers likely to have windfall profits as the retail price margin in creased relative to the farm and wholesale levels; and (c) disease outbreaks affect dynamic price interdependence.

JEL classification: C32; Q11; L11

Key Words: Animal disease outbreak, Error correction model, Direct acyclic graphs, Korean meat market; Historical Decomposition; Price margins

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The Impacts of Animal Disease Crises on the Korean Meat Market

There has been a long-standing concern related to animal disease since bovine spongiform encephalopathy (BSE) was first discovered in the United Kingdom in 1986. This concern has been increasing since the United Kingdom announced a possible link of BSE and the human version of the virus, vCJD, in 1996. Animal disease related food scares, especially when disease can spread to humans, alter meat consumption and meat prices along with the loss of consumer confidence in food safety and the resulted distortion in meat supply. The adverse impacts of animal disease outbreaks are beyond domestic phenomena 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, and shocks from localized animal disease outbreaks can be quickly transmitted to other regions and countries. For example, the BSE discovery in the United Kingdom in 1996 caused disruptions in meat markets world wide (Kenneth et al., 2002).

In this study we investigate the impacts of animal disease outbreaks on the Korean meat market. Since the of turn of the century, the Korean meat market has been affected by three animal disease outbreaks: a FMD (Foot and Mouth Disease) outbreak in Korea in April 2000, an AI (Avian Influenza) outbreak in Korea in December 2003, and the first BSE discovery in the U.S. in December 2003. We did not consider BSE discoveries in Canada and the United Kingdom since Korea imports meat mainly from the United States. Korea banned beef imports from the U.S. immediately after the 2003 U.S. BSE discovery, and it did not lift the import ban till July, 2007 when boneless beef could again be imported from the U.S. to Korea. Thus, we did not consider the BSE discoveries in the U.S. in 2005.

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 meat 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 versus oversea). Hence, we are able to investigate differential impacts. 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, the majority of literature investigates impacts of animal disease outbreaks on meat markets in the U.S., Canada, and European countries. There are some studies that investigate Japanese markets responding to food scares (Jin et al., 2003; McCluskey et al., 2005; Peterson and Chen, 2005; Saghaian et al., 2007). Song and Chae (2007) is the first attempt to examine the impacts of BSE on the Korea meat market (written in Korean). In particular, they estimate the social loss from the U.S. BSE outbreaks. Other than that, to our knowledge there is no study that systematically investigates the Korean meat market. This study will fill this gap and provide another country specific analysis.

The rest of the paper is organized as follows. In the next section, we present a literature review on food safety and animal disease-related food scares. We then present time series analysis, including ECM and historical decomposition of price innovations, in section 3. We provide an overview of the Korean meat market and the market responses to animal disease outbreaks in section 4 and discuss the data in section 5. Empirical results are presented in section 6, and conclusions are discussed in the last section.

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. The larger demand responses correspond to major food scare shocks, 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 in September 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 month after the Japanese BSE discovery. Using a unique UPC-level scanner data set, Schlenker and Villa Boss (2006) find a pronounced and significant reduction in beef sales following the first BSE discovery in the U.S, 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) find that beef prices at the retail, wholesale and producer levels in the United Kingdom are estimated to have fallen by 1.7, 2.25, and 3.0 pence per kilogram in the long-run after the British government in 1996 announced a possible link between BSE and it's human version, vCJD. Pritchet et al. (2005) argue that the 2003 US BSE discovery led to a 14% decrease in the choice boxed beef price and a 20% decrease in the fed cattle price between December 22nd 2003 and January 8th 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.

There is a broad literature on the farm and retail price margin and what factors may influence price transmission since Gardner's (1975) work. However, the literature on price transmission affected by animal disease is relative thin. Using Johansen's cointegration approach, Sanjuan and Dawson (2003) find that retail-to-farm price margin of beef increased following the BSE discovery in 1996. Similar increases were not found in the lamb and pork markets. Lloyd et al. (2006) find that the impact of BSE on farm price is much bigger than retail price and, hence, the retail-to-farm price margin became wider due to the 1996 UK BSE discovery.

Other studies investigate the impact of food scares on prices of stock, equity, and futures in commodity markets (Salin and Hooker, 2001; Wang et al., 2002; Henson and Mazzocchi, 2002; Lusk and Schroeder, 2002). Henson and Mazzocchi (2002) find that the BSE discovery in 1996 had a negative and immediate impact on the equity prices of 24 companies in the United Kingdom. Lusk and Schroeder (2002) find that beef and pork recalls only have marginal effects on live cattle and hog futures prices. Schlenker and Villas-Boas (2006) find that futures prices have a comparable drop compared with the estimated price change using the scanner data, but contracts with longer maturity have a smaller price drop response to the first U.S. BSE discovery.

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

ECONOMETRIC MODEL

To identify and quantify the impacts of animal disease outbreaks on the Korean meat market we employ time series methods, mainly the error correction model (ECM), and historical decomposition of price innovations. The ECM will allow 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 margin along the supply chain. However, the comparison cannot illustrate dynamic changes in the meat price system due to disease outbreaks. In other words, due to substitution between different meat types and the supply chain integration, an animal disease outbreak will potentially affect meat consumptions and meat prices at all the levels within the supply chain. We expect that the net impacts on a certain price series, say, the retail beef price, come from the own-price changes as well as the changes of other meat prices. We use a historical decomposition of price innovations 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.

Error Correction Model

We denote the total number of price series of interest by I 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 a $I \times 1$ vector of price series, can be modeled in ECM with k-1 lags:

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

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

$$\Delta X_t = [\Pi, \mu]\begin{bmatrix} X_{t-1} \\ 1 \end{bmatrix} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + e_t ; \quad \text{with linear trend} \qquad (2a)$$

$$\Delta X_t = [\Pi, \mu_1, \mu_2]\begin{bmatrix} X_{t-1} \\ 1 \\ t-1 \end{bmatrix} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + e_t ; \quad \text{without linear trend} \qquad (2b)$$

where μ, μ_1, and μ_2 are $I \times 1$ 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 first approach is a two-step procedure involving system-based likelihood ratio (LR) tests. The procedure is as follows: (a) determine the number of lags using information matrices such as Schwarz-loss criterion (SIC), Akaike information criterion (AIC), Hannan and Quinn-loss (HQ), and Hacker and Hatemi-J (HJ) metrics; and (b) given the optimal lag length, determine the rank of cointergration vectors based on a trace test (Johansen, 1988, 1991) with test statistic given by

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

where T is the number of observations and λ_i's are ordered eigenvalues of matrix Π in equations (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, the two-step procedure might not be free from a model specification problem which ultimately involves a trade-off between model parsimony and fit, given the fact that the true model is rarely known (Wang and Bessler, 2005). Boswijk and Franses (1992) state that the choice of lag length in a VAR model in the first step has an important impact on the cointegration test performance.

Recently, model selection methods based on information criteria have been proposed and implemented as an alternative and a robustness test for conventional two-step procedure in Johansen type's VECM specification (Phillips and McFarland, 1997; Aznar and Salvador, 2002; Kapetanious, 2004; and Baltagi and Wang, 2007). There are at least three advantages of the model selection method compared with system-based LR tests. First, it is possible to jointly estimate 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 appropriate significance level in contrast with formal hypothesis testing such as system-based LR tests. Third, Chao and Phillips (1999) and Wang and Bessler (2005) provide simulation evidences to show 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 SIC loss may have a tendency to over-penalize additional regressors in contrast to other metrics. Hannan and Quinn (1979) suggest that HQ 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,

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

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.

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, 2007) or the 1987 US stock market crash (Yang and Bessler, 2008). We employ historical decomposition methodology 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 expresses equation (1) into moving average presentation,

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

where the matrix Θ_0 summarizes the contemporaneous causal patterns between innovations, and ε_t are contemporaneous orthogonal innovations. The price innovations estimated from the ECM estimation e_t may exhibit off-orthogonal contemporaneous correlations. We need to convert e_t into the orthogonal innovations ε_t before conducting historical decomposition.

(1) Convert into the orthogonal contemporaneous price innovations

A structural factorization is employed to covert the innovations from the ECM estimation (e_t) into the orthogonal contemporaneous price innovations (ε_t), such that

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

Choleski factorization, as one of the widely used methods, assumes a recursive contemporaneous causal structure and considers higher ordered variables as relatively more exogenous. As stated by Demiralp and Hoover (2003), one drawback of Choleski factorization is that it allows researchers to arbitrarily choose one case among the various possible causal stories that may not reflect "true" contemporaneous causal ordering among variables.

Recently, several efforts using directed acyclic graphs (DAGs) are made in VAR-type model identification (Swanson and Granger, 1997; Spirtes and Scheines, 2000; Pearl, 2000; Bessler and Lee, 2002). DAGs are less *ad hoc* to uncover contemporaneous causal orderings that is determined by data itself compared to the arbitrary ordering by the Choleski decomposition. Another advantage of using DAGs is that the results based on data can be compared to a priori knowledge of a structural model suggested by economic theory or subjective intuition.

DAG is a picture summarizing causal flows among a set of variables. Arrows represent the direction of information flow between variables, but no arrow is allowed to direct from one variable all the way back toward itself. The graph starts with undirected edges connecting the variables. The assignment of the directions to the edges is based on the concept of *d-separation* that is more understandable in the screening-off phenomenon (Pearl, 2000). DAGs represent conditional independent relationship as implied by the recursive product decomposition:

$$\Pr(x_1, x_2, x_3, \ldots\ldots, x_n) = \prod_{i=1}^{n} \Pr(x_i \mid pa_i), \tag{7}$$

where $\Pr(\cdot)$ is the joint probability of variables $x_1, x_2, x_3, \ldots\ldots, x_n$ and pa_i is the realization of some subset of the variables that cause x_i in order $(x_1, x_2, x_3, \ldots\ldots, x_n)$.

We use the greedy equivalent search (GES) algorithm given in Chickering (2002) to generate DAGs. The GES algorithm employs a two-stage stepwise search according to the Bayesian Information Criterion approximation from Schwarz:

$$\mathrm{S}(\mathrm{G}, \mathrm{D}) = \ln p(D \mid \hat{\theta}, G^k) - \frac{d}{2} \ln T, \tag{8}$$

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 directed acyclic graph G, T is the number of observations, and D is the data available to researchers. The scoring criterion considers the trade-off between fit represented by $\ln p(D \mid \hat{\theta}, G^k)$ and parsimony modeled by the term $\frac{d}{2} \ln T$. The GES algorithms 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). The GES algorithm follows with a two-step 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 increasing 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 step where the equivalence class that leads to a local maximum is chosen. The two-stage procedure is repeated until no further additions or deletions of edges to improve the score. More details on the GES algorithms are given in Chickering (2002, p. 520-24)

(2) Historical decomposition of orthogonal price innovations

Once the price innovations from the ECM estimation are converted into the diagonal innovations, the historical decomposition of the vector *X* at particular time $t=T+k$ can be divided into two parts:

$$X_{T+k} = \sum_{s=k}^{\infty} \Theta_s \varepsilon_{T+k-s} + \sum_{s=0}^{k-1} \Theta_s \varepsilon_{T+k-s} \,. \tag{9}$$

The first term in the right-hand side of equation (9), called the "base projection", utilizes information available up to time period *T*. The second term contains information available from time period $T + 1$ until $T + k$ including the animal disease outbreaks. The base projection that utilizes information available up to time period *T* is unlikely to coincide with the actual X_{T+k} since additional information from time period $T + 1$ to $T + k$ that influences the actual X_{T+k} is purposely left out. Therefore, the difference between the actual price $\left(X_{T+k}\right)$ and the base price projection $\left(\sum_{s=k}^{\infty} \Theta_s \varepsilon_{T+k-s}\right)$ is contributed to the innovations of all the price series $\left(\sum_{s=0}^{k-1} \Theta_s \varepsilon_{T+k-s}\right)$. Through the partition, historical decomposition allows us to examine the behavior of each price series in the neighborhood of important historical events (animal disease outbreaks in our cases) and to infer how much each innovation contributes to the unexpected variation of X_{T+k}.

KOREAN MEAT MARKET AND ANIMAL DISEASE OUTBREAKS [1]

Korean meat market has been continuously expanded along with increasing per capita income. The total aggregate production value of the livestock industry is $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 kilogram in 1990 to 32 kilogram 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 is becoming one of the major players in international trade. As of 2003, Korea is the ninth largest meat importing country and the fourth largest beef import country in the world. In particular, among all the countries that importing meat products from the U.S., Korea is the second largest for beef ($816 million), the fourth for pork ($79 million), and the sixth for poultry ($50 million) (Henneberry and Hwang, 2007).

Korea significantly relies on imports to meet the increasing meat demand. The total quantity of imported beef doubled from 1996 to 2003 and the self-sufficiency decreased from 53.5% to 36.3% in the same period. Pork consumption constitutes more than half of the meat consumption in Korea. The leading pork export countries to Korea are the U.S., 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 instead of red meat. Korea mainly imports chicken from Demark, the U.S., and China.

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[1] All the data mentioned in this section are from an internal report by the Ministry of Agricultural and Forest of Korea except that cited from literature.

To satisfy the growing consumer concern about food safety and quality, the Korea government implemented a mandatory "Hazard Analysis and Critical Control Points (HACCP)" program in meat supply chain in 1997. "Country of Origin (COA)" has been brought into the Korea market since 1999. Meanwhile, domestic meat producers and retailers have been adopting various market strategies to differentiate their product and to meet demand of certain consumer segments including, but not limited to, product certificate programs and branding.

Since Korea exhibits significant import dependence, it takes on risk from animal disease outbreaks in exporting countries in additional to domestic incidents. The Korean meat market has faced several significant animal diseases outbreaks that have occurred in or out of the country and caused disruptions in the meat market since 2000. The largest outbreak case of FMD in Korea was discovered in a dairy cow farm in Paju county, Kyonggi province, north of Seoul on March 25, 2000. 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. Korean National Veterinary Research and Quarantine Service restricted the movement of all animals and animal related products within a 20 kilometers radius of the outbreak farms to avoid further spread of FMD. As a result, a total of 2,216 head of livestock (cow, hog, and lamb) were slaughtered by the end of April, 2000; the estimated total direct cost amounts to $404 million; the Korea government spent more than $7 million to compensate for livestock loss and purchase back the overstocked pork to protect farmers. In response, Japan imposed an import ban of a total of 80,265 metric tons of pork from Korea.

The first AI case was reported in a Korean native chicken farm in Umsong county, Chungbuk province on December 10, 2003, followed by eighteen more AI cases diagnosed nation wide. As contagious as FMD, AI imposes a threat to humans while FMD does not typically affect humans. As a result of the AI incidents 5,283,493 head of poultry (mainly chicken) were slaughtered along with vaccination and movement restriction of animals and humans in the affected zones. Chicken consumption fell down by 30%. The estimated total direct cost is over $137 million.

In contrast with the AI and FMD outbreaks, BSE has not been discovered in Korea. However, the U.S. is the largest country that exports beef to Korea. In 2003, beef imported from the U.S. accounted for 68% of the total beef imported and 44% of the total beef consumption in Korea. Generally, animal disease outbreaks overseas affect the domestic meat market in two ways: (a) loss of consumer confidence that decreases the consumption of imported meat but may increase the demand for disease free domestic meat; and (b) trade disruptions that lead to the change on the supply side. Following the US BSE discovery in December 2003, Korea banned imports of beef and offal from the U.S.,[2] and Australia became the largest beef importing country accounting for over 75% of beef imports since 2004. Beef consumption in Korea dropped by 16% in response to simultaneous reduction of beef demand and supply. The consumption of imported beef fell by 27% in 2004 due to consumer concern over food safety and fell more in 2005. In contrast, domestic beef consumption has had little change, and rather slightly increased in the same period. Meanwhile, the pork imports had a substantial increase of 185% from 2003 to 2005, which suggests a significant substitution to pork.

[2] The import ban has not been lifted until July, 2007. Starting from July, 2007, boneless beef is allowed to import from the U.S. to Korean.

DATA

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. Data are retail beef price (RB), wholesale beef price (WB), farm beef price (FB), retail pork price (RP), wholesale pork price (WP), farm pork price (FP), retail chicken price (RC), wholesale chicken price (WC), and farm chicken price (FC). All series are provided by Korea Agro-Fisheries Trade Corporation (KAFTC). Figure 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.

EMPIRICAL FINDINGS AND DISCUSSIONS

Before we conduct the ECM estimation we test for non-stationarity of each price series using Dickey Fuller (DF) tests and Augmented Dickey Fuller (ADF) tests. For the ADF test, the optimal lag length was determined by minimizing Schwarz-loss information metric. The results in Table 1 suggest that all the price series, except the chicken prices at the farm and wholesale level (FC and WP) and the wholesale pork price (WP), are non-stationary at the 5% significance level. However, the first order difference of each price series is stationary.

As we discussed in section 3, we can either use the two-step procedure to determine the optimal lag length (k) and the rank of cointegration vectors (r) separately using system-based LR tests, or use the one-step procedure to jointly determine k and r using information criteria metrics. As shown in Table 2, SIC, HQ, and HJ metrics suggest a level 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 SIC may have tendency to over-penalize additional regressors in contrast to other metrics (Geweke and Meese, 1981), we conclude a level VAR with two lags, which corresponds to one lagged difference in the ECM estimation, i.e., $k = 2$ in equation (1). The trace test results in Table 3 show that we reject the null hypothesis at $r=0, r \leq 1$, and $r \leq 2$ at the 1% significance level and fail to reject the null hypothesis $r \leq 3$ at the 5% significance level for both specifications (with or without linear trend). The test results suggest that three cointegrating vectors exist in the cointegrating space. Following the one-step procedure, we conclude that the optimal lag length is two and the rank of cointegrating vectors is three since this combination gives the lowest HQ loss metric (see Figure 2). Therefore, the optimal lag length and the rank of cointegration vectors are the same using these two procedures, which is consistent with Wang and Bessler's finding (2005).

Since the possible structural change will affect the performance of forecasting, we implement trace tests based on time-varying rolling cointegration methods for any structural changes. The results of normalized trace tests suggest a significant structural change occurred in 2000 that is likely induced by the 2000 FMD outbreak.

The Impacts of Animal Disease Outbreaks on the Korean Meat Prices

Since the domestic FMD outbreak occurred in April 2000, we first estimate ECM using the information from January 1985 to March 2000 and then conduct out-of-sample forecasting of meat prices of 44 months after the event before the next animal disease outbreak occurred, i.e., from April 2000 to November 2003.[3]

[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). Meanwhile, moving average parameters, Θ, for base projection and contribution in equation (9) associated with historical decomposition are fitted by in-sample procedure as programmed in RATS.

In addition, since the domestic AI incidents and the US BSE discovery are occurred in December 2003 we also need to quantify the impacts of both diseases following the same procedure applied to 2000 FMD outbreak. There are two options we can take to estimate the ECM and then conduct out-of-sample forecasting of meat prices of 37 months from December 2003 to December 2006: (a) a large sample case in which we use the information from January 1985 to November 2003 despite of the structural break induced by the FMD outbreak in April 2000; and (b) a small sample case in which we use the information only after the FMD outbreak, i.e. from May 2000 to November 2003 to avoid the impacts of the structure change. Whether the large or small sample case leads to a better forecast depends on the tradeoff between the confounding impacts of the FMD outbreak and the sample size. We conduct forecast performance tests between the two options. The results of mean square forecasting error (MSFE) report that the large sample model has a lower MSFE than the small sample model in all horizons except for farm beef in the three-month horizon, farm pork and wholesale pork in the five-month horizon, and retail pork (RP) in three to the five-month horizon. To investigate the statistical difference between these two forecasting errors, we employ modified Diebold-Mariano test (Harvey et. al, 1997) at one-step ahead forecast. The null hypothesis is that the means squared errors between the large and small sample ECM models are the same, i.e., $MSE_{big} - MSE_{small} = 0$. The *t*-statistics from the DM tests are 2.525 (FB), 2.014 (FP), 2.427 (FC), 2.015 (WB), 1.014 (WP), 1.832 (WC), 2.240 (RB), 2.182 (RP), 2.135 (RC), which are greater than the critical value of Student *t*-distribution at the 5% significance level (1.690, *df* = 36). Hence, we reject the null hypotheses are rejected at the 5% significance level in all cases except wholesale pork and fed cattle prices. We then conclude that the large sample ECM model gives a better forecast despite of the structural change induced by the domestic FMD in April 2000. Thus, we choose the large sample ECM model.

We denote by x_{ij}^{d} and F_{ij}^{d} the actual and forecasted meat 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). We then construct the percent change of the actual price relative to the forecasted price,

$$\Delta P_{ij}^{d} = \frac{x_{ij}^{d} - F_{ij}^{d}}{F_{ij}^{d}} \times 100 \cdot \qquad (10)$$

(1) The impacts of the domestic FMD outbreak on the meat prices

Figure 3 illustrates ΔP_{ij}^{FMD} over time for beef, pork, and chicken at the farm, wholesale, and retail levels following the domestic FMD outbreak in April 2000. Figures (3a) and (3b) suggests 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 price. However, the magnitude and timing of the changes were different in these two markets. The initial 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 farm pork price and 13% for the farm beef price, and up to 38% for the wholesale pork price and 4% for the wholesale beef price). The retail beef price recovered eight months after the event, but the price recovery at the farm and whole levels were almost six months behind. Overall, the beef market appeared to have recovered 16 months after the event. Figure (3b) suggests that the 2000 FMD outbreak had long term adverse impacts on the farm and wholesale pork prices -- the prices did not recover for over 44 months after the disease outbreak. The long run impacts on the farm and wholesale price may due to the disruption on the production cycles.

In contrast to beef and pork prices, chicken, as a substitute of beef and pork, benefited from the outbreak and its prices increased up to 34% for the farm and wholesale prices and up to 10% for the retail prices between the second and the eighth month. However, the substitution seems not to be permanent since the chicken prices went down after the beef and pork markets rebounded.

(2) The impacts of the AI/BSE incidents in December 2003 on meat prices

Figure 4 illustrates the percentage change of price, ΔP_{ij}^{AB} , for beef, pork, and chicken at the farm, wholesale, and retail levels following the 2003 Korean AI and the U.S. BSE events.

Immediately after the BSE discovery in the U.S., Korea banned beef import from the U.S., which caused the total imported beef to drop by 71% in January 2004 compared to the previous year. The import ban may have lead to a demand increase for domestic produced beef, which may have increased the prices of domestic produced beef. On the other hand, consumers have been reluctant to consume beef, since they may have not felt secure about beef, regardless of whether it was imported or domestically produced. 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 in Korea. As shown in Figure (4a), the retail beef price decreased by 10% in the 10^{th} month, which suggests that the impact on the demand side dominates. The concern over the safety beef consumption among consumers might be one of the main factors that caused a substantial decrease in prices of domestic 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. Figure (4a) also shows an immediate, sharp price drop at the farm and wholesale levels following the animal disease incidents. The farm and wholesale beef prices decreased by 28% in the sixth month after the incidents and, then, 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 incidents.

Figure (4c) shows that chicken prices rebounded shortly following a substantial, immediate price fall after the incidents. The recovery of chicken prices in a short period from the AI shock may be contributed to the promotion campaign of chicken consumption and reopened trade of heated chicken meat products in July 2004 as well as the substitution of beef with chicken due to the US BSE discovery. Figure (4b) clearly shows that the pork market gained from the incidents as the prices increased, which may be contributed to consumption substitution.

(3) Differentiate impacts between two incidents in 2000 and 20003

Both FMD and BSE directly affect the Korean beef market as cattle are vulnerable to both diseases. If we compare figures (3) and (4), we note that the impact of the 2003 BSE outbreak occurred in the oversea market was greater than that of the 2000 FMD outbreak in Korea. First, the initial beef price drop at the farm, wholesale, and retail levels within the first six months was much bigger following the BSE discovery than the FMD outbreak. Second, the price recovery came earlier in the BSE case (approximately 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 discovery.

FMD directly affects the pork market. Pork prices decreased following the FMD outbreak and the farm and wholesale pork prices did not recover in the 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 due 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.

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. The retail-to-farm price margin $PM^d_{i,rf}$ that is affected by animal disease outbreak *d* is $x^d_{ir} - x^d_{if}$, and it is $F^d_{ir} - F^d_{if}$ if there is no disease outbreak. Therefore, the change of the retail-to-farm price margin due to animal disease outbreak *d* is written in equation (11a). Similarly, the change of the wholesale-to-farm and the retail-to-wholesale price margin are in equations (11b) and (11c), respectively.

$$PM^d_{i,rf} = \left(x^d_{ir} - x^d_{if}\right) - \left(F^d_{ir} - F^d_{if}\right), \qquad \text{retail-to-farm} \qquad (11a)$$

$$PM^d_{i,wf} = \left(x^d_{iw} - x^d_{if}\right) - \left(F^d_{iw} - F^d_{if}\right), \qquad \text{wholesale-to-farm} \qquad (11b)$$

$$PM^d_{i,rw} = \left(x^d_{ir} - x^d_{iw}\right) - \left(F^d_{ir} - F^d_{iw}\right). \qquad \text{retail-to-wholesale} \qquad (11c)$$

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

(1) The impacts of the 2000 FMD outbreak on the price margins

Figure 5 shows the change in the price margins resulting from the FMD outbreak in April 2000. The results suggest that the price margins along the supply chain stayed almost constant for six month after the FMD outbreak for beef or three months for pork. After this period, the price margin at the retail level relative to the farm and wholesale levels started to increase. This finding 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 contributed to the market power in the retail level. According to the Korean Statistical Information Service (KOSIS), there are approximately 250 stores in Korea that have 100 employees and up, and these stores are owned only by five companies (Shinsegae E-mart, Lotte mart, Carrefour, Samsung Home-Plus, Wal-Mart [4]). The 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, and retailers may use their market power to gain from the disease outbreaks.

(2) The impacts of the 2003 AI/BSE incidents on the price margins

Following the AI/BSE incidents consumers may substitute beef and chicken with pork and, hence, 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 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 then decreased, and finally increased starting from the 13th month after the incidents (at which the beef prices started to rebound).

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

The Impacts of Animal Disease Outbreaks on Dynamic Price Interdependence

The analysis so far did not say anything about the change in interdependence among price series due to animal disease outbreaks. We employ historical decomposition to evaluate how much each price innovation accounts for the atypical variation of a certain price series due to animal disease shocks.

The contemporaneous correlation matrix of price innovations estimated from the ECM in Figure 7 shows positive correlations between innovations of any two price series except FB and FP, FB and WP, WB and FC, WB and WC, WB and RC. We also find strong correlations between prices in the pork or chicken market, suggesting that innovations in the pork or chicken market quickly transmitted into other levels within the supply chain. However, the beef market had relatively weak correlations along the supply chain.

Using the correlation matrix in Figure 7, we employ TETRAD IV with the GES algorithm to identify the causal flows between contemporaneous price innovations.[5] The results in Figure 8 suggest the innovations of the farm level prices directly affected the wholesale prices in three meat markets. The innovation of the chicken price at the farm level 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 in 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.

[5] TETRAD IV available at http://www.phil.cmu.edu/projects/tetrad.

Historical decomposition of each series is implemented over 23 months, including two months before each event, the month the incident occurred, and 20 months following the event. The bar chart in Figure 9 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. 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 periods. Figure 9(a) 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 was diminishing and was being replaced by the contributions from the retail beef, retail pork, and farm chicken price. This is reasonable since the supply shock occurred in first as the Korean government slaughtered infected cattle immediately after the event. Figure 9(b) shows that the farm beef price innovation had a significant negative contribution to the retail beef price innovation, followed by the wholesale chicken price following the 2003 AI/BSE incidents. The basic message of Figure 9 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.

Similar figures of historical decomposition are available upon request. 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, and the other innovations had minimal influences on the farm 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 the contribution of the wholesale price innovation itself was relatively small. While in the case of the 2000 FMD outbreak, the wholesale pork price almost solely contributed to its upward pressure. 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.

CONCLUSION AND FUTURE RESEARCH

Employing time series methods, mainly the error correction model and historical decomposition of price innovation, accompanied by directed acyclic graphs, we identify and quantify the impacts of domestic (FMD and AI) or overseas (BSE) animal disease crises on the Korean meat supply chain using monthly prices of beef, pork, and chicken at farm, wholesale, and retail level from January, 1985 to December, 2006.

Overall, the domestic FMD outbreak in 2000 induced a structural change in the Korean meat price system. However, the domestic AI incidents and the U.S. BSE discovery in 2003 did not lead to any significant structural change. We summarize the main findings of the impacts of the domestic and oversea animal disease outbreaks on prices, price margins, and price interdependences in the Korean meat system below.

First, we find that animal disease outbreaks caused a temporary price shock to the Korean meat market regardless of whether it is 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 finally 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 contributed to the supply disruptions. Furthermore, the AI/BSE incidents led to more significant changes in beef prices in the first six shock periods compared with the FMD outbreak. The pork market gained from the AI/BSE incidents due to consumption substitution, but the gain was short-lived.

Second, 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 when market power exists as suggested by Lloyd et al. (2006). In addition, we discover that the wholesale-to-farm price margin was relatively stable. Therefore, the analysis on price margin indicates that both animal disease outbreaks triggered asymmetric price transmission in the Korean meat supply chain and the retail sector had a windfall price gain.

Third, 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. Right after 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 U.S. 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 other price series in the long term.

This study makes the following 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 country of origin (domestic versus oversea). Hence, we are able to investigate differentiated impacts. 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 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 the U.S., Canada, Europe, and Japan markets. To our knowledge there is no study 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. Secondly, animal disease outbreaks cause supply disruptions, for example, a mass slaughter of cattle in the even 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 more broad system including imported meat price 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 the direction for future research.

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Table 1. Tests for non-stationarity 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)**

Note: The asterisks, * and **, indicate 5% and 1% significance level. The critical value is -2.89 at the 5% significance level and -3.51 at the 1% level. Schwarz information criterion, SIC = $\ln(\det \hat{\Omega}_k) + k\left(\frac{\ln T}{T}\right)$, 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 of Ω, T is the sample size, and *k* is the lag length.

Table 2. 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

Information criteria metrics used to identify the optimal lag length (k) of a level VAR are SIC = $\ln(\det\hat{\Omega}_k)+k\left(\frac{n\ln T}{T}\right)$; AIC = $\ln(\det\hat{\Omega}_k)+k\left(\frac{2n}{T}\right)$;

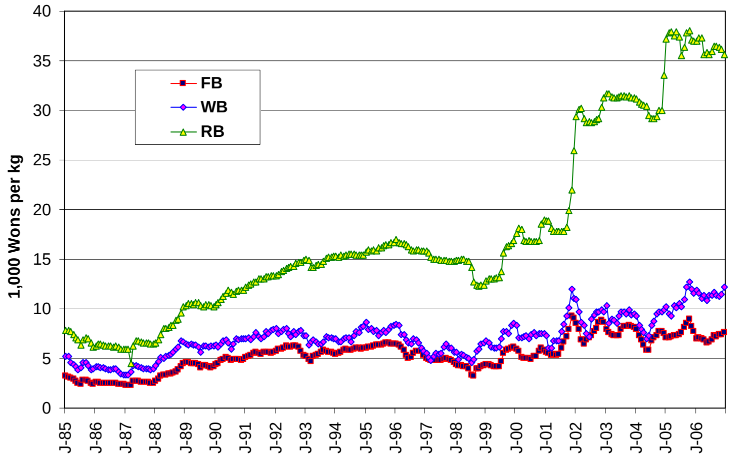
HQ = $\ln(\det\hat{\Omega}_k)+k\left(\frac{2n\ln(\ln T)}{T}\right)$; and HJ = $\ln(\det\hat{\Omega}_k)+k\left(\frac{n\ln T+2n\ln(\ln T)}{T}\right)$;

where $\hat{\Omega}_k$ is the maximum likelihood estimate of variance-covariance matrix of Ω, k is the proposed lag length, n is the number of variables, and T is the sample size.

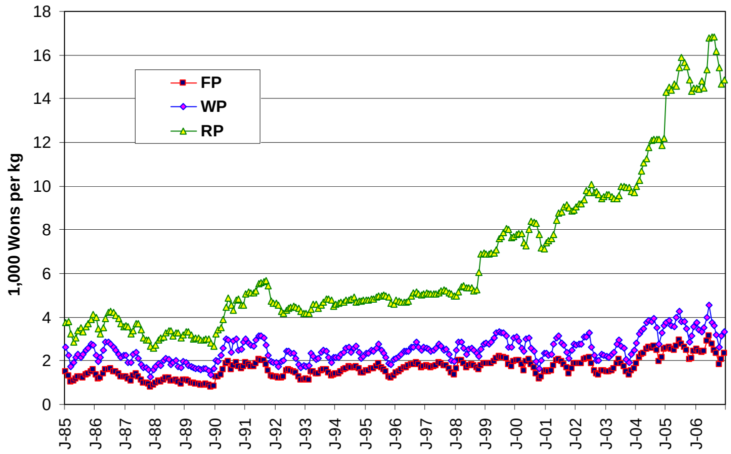
Table 3. Trace tests for ECM under two specifications of deterministic term

Rank	Without linear trend				With linear trend			
	Trace statistics	Critical value 1%	Critical value 5%	Test decision	Trace statistics	Critical value 1%	Critical value 5%	Test decision
r = 0	297.54	220.99	208.27	R	287.50	209.58	197.22	R
r = 1	212.27	180.95	169.41	R	204.63	170.5	159.32	R
r = 2	139.09	144.91	134.54	R	131.65	135.43	125.42	R
r = 3	89.08	112.88	103.68	F	82.27	104.36	95.51	F

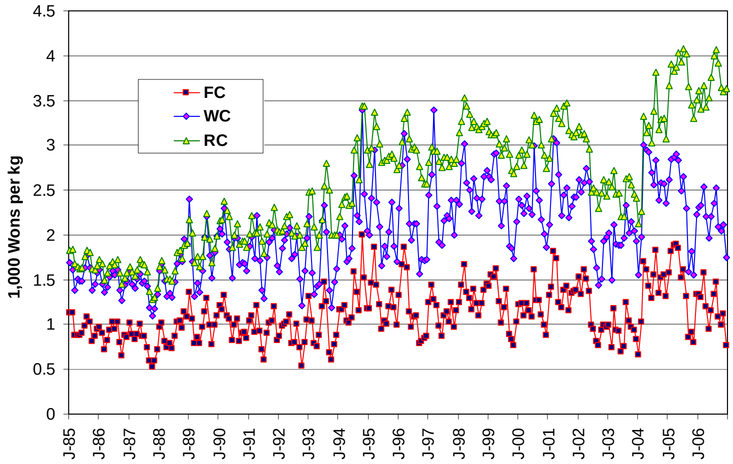
Note: The testing for the higher order rank is stopped at the first time when we fail to reject the null hypothesis. The corresponding critical values are taken from *CATS in RATS* , *Volume 2* manual by Dennis (2006). See Table B.2 for Critical value* and Table B.3 for Critical Value. R and F stand for "reject the null hypothesis" and "fail to reject the null hypothesis", respectively.



(a) Beef



(b) Pork



(c) Chicken

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

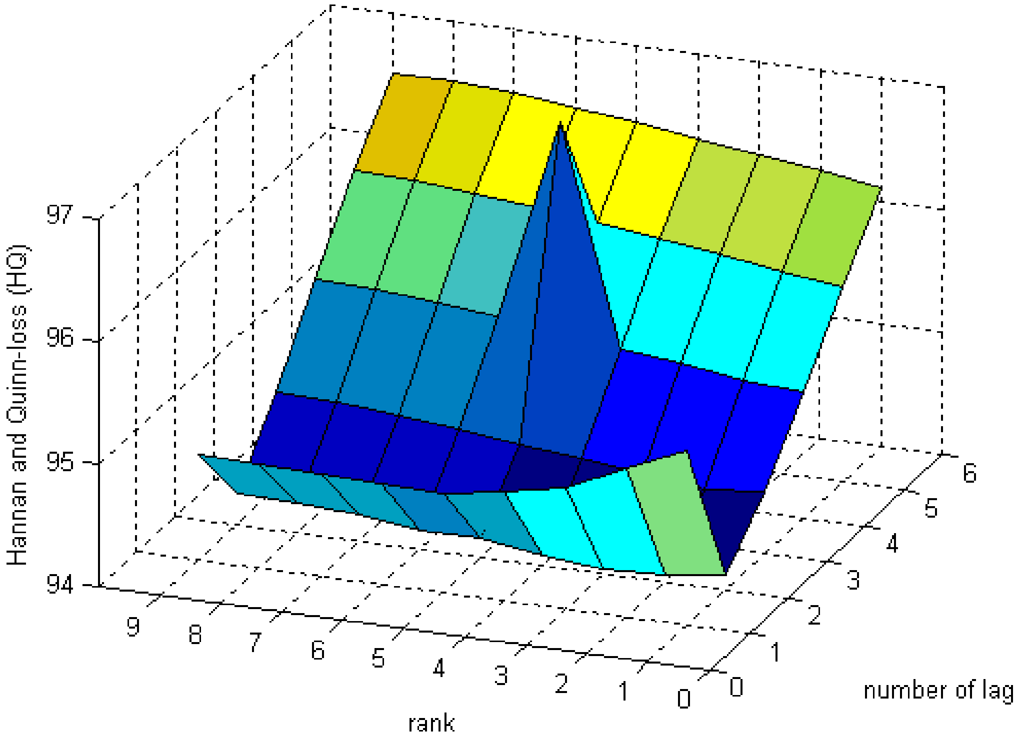
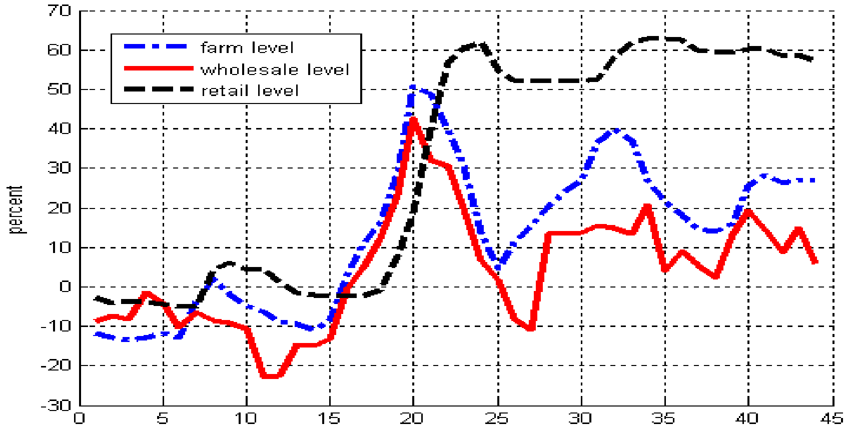
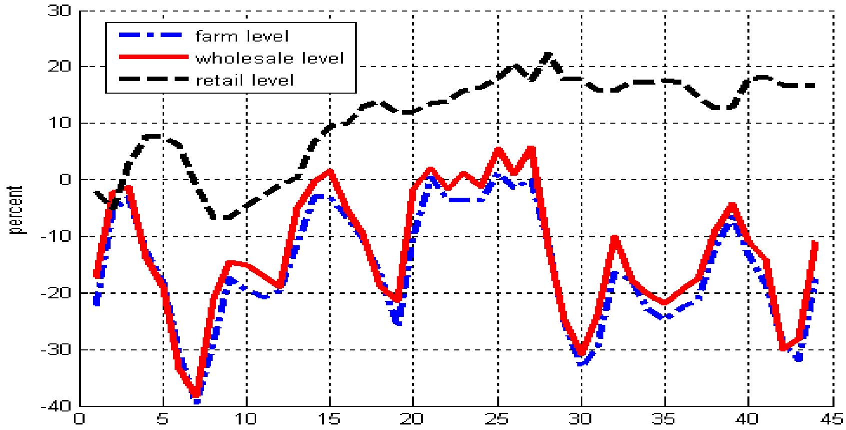


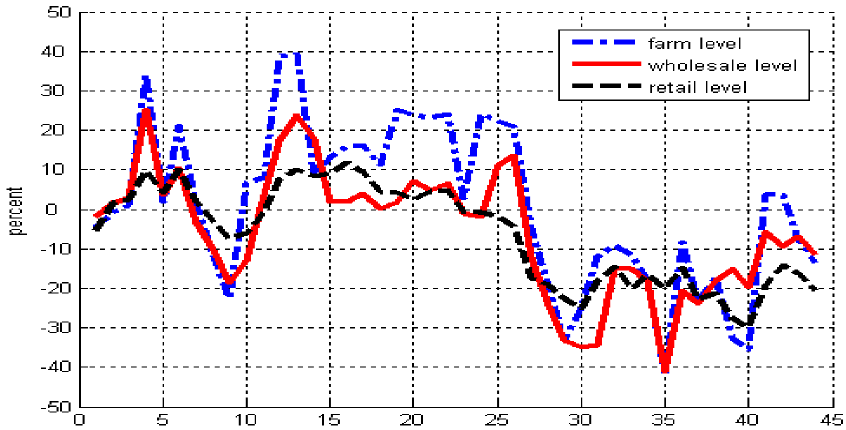
Figure 2. Hannan and Quinn (HQ) loss given different combinations of cointegration ranks (*r*) and lag length (*k*)



(a) Beef

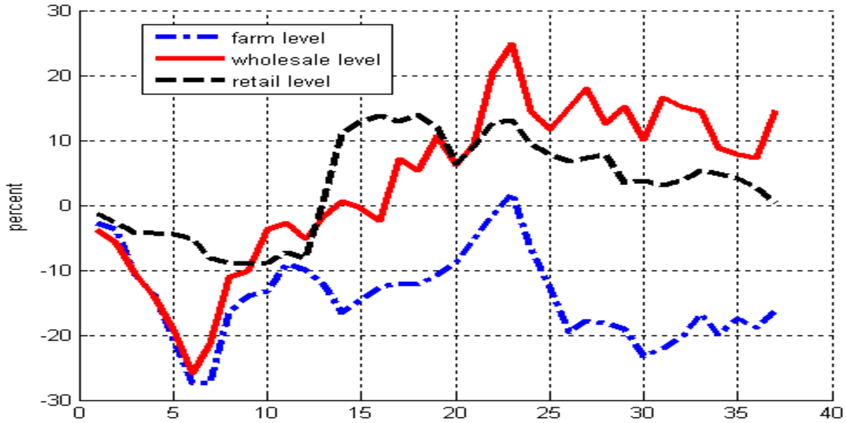


(b) Pork

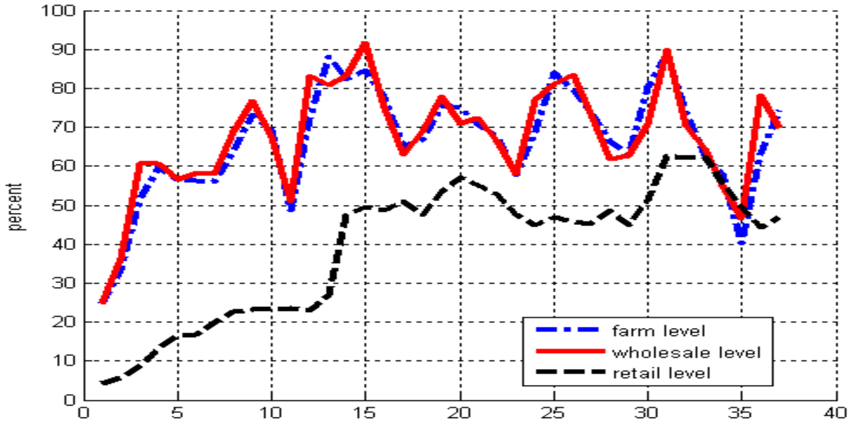


(c) Chicken

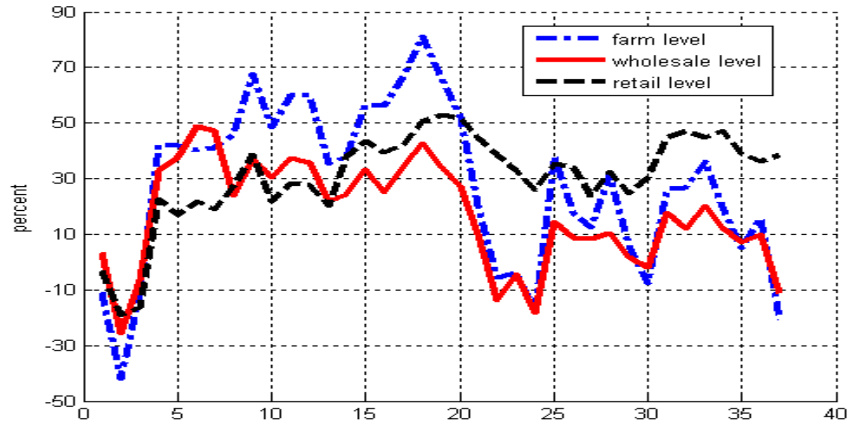
Figure 3. Percentage change of the actual price relative to the forecasted price following the FMD outbreak in April 2000 and before the AI/BSE incidents in December 2003 (The x-axis is the number of months after the 2000 FMD outbreak)



(a) Beef

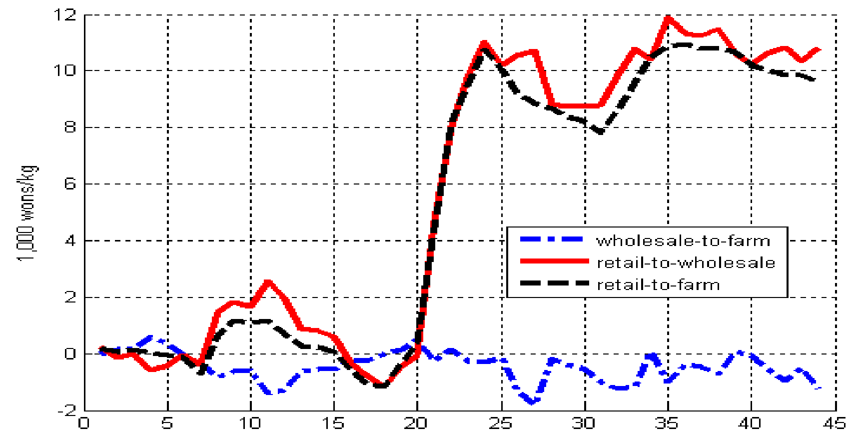


(b) Pork

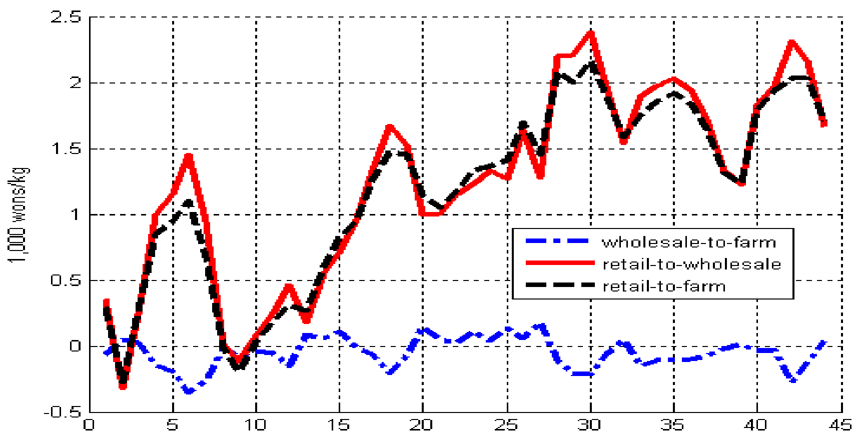


(c) Chicken

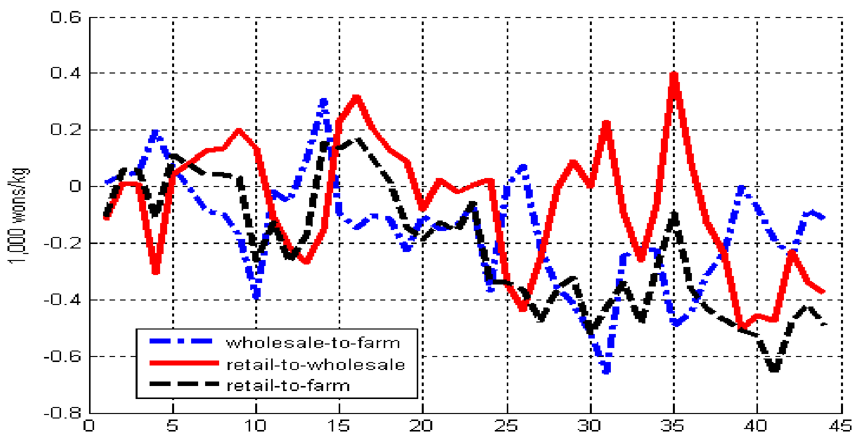
Figure 4. Percentage change of the actual price relative to the forecasted price following the AI/BSE incidents in December 2003 (The x-axis is the number of months after the incidents)



(a) Beef

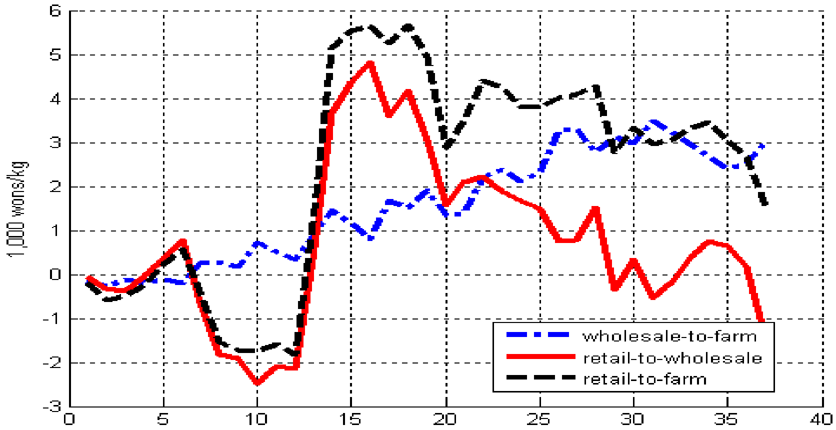


(b) Pork

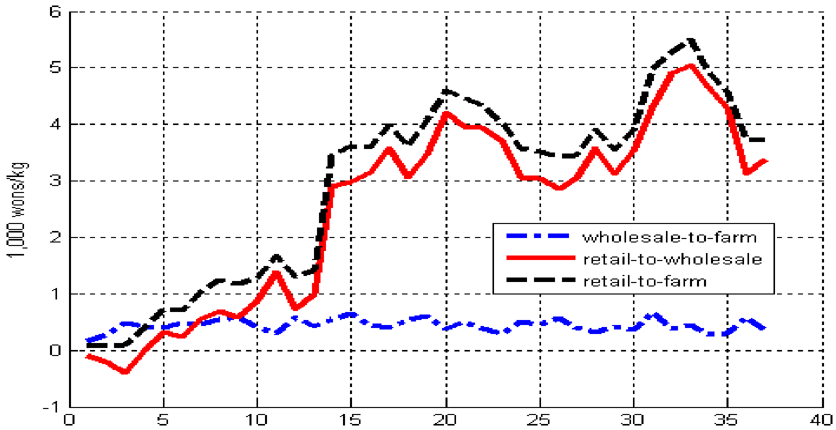


(c) Chicken

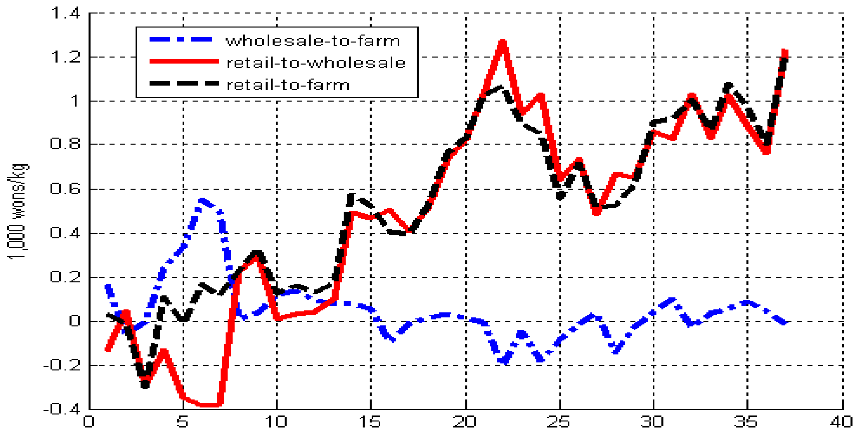
Figure 5. Changes in the price margin along the supply chain following the FMD outbreak in April 2000 and before the BSE/AI incidents in December 2003 (The x-axis is the number of month after the event)



(a) Beef



(b) Pork



(c) Chicken

Figure 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)

$$
\begin{array}{c}
\\
\Omega\left(\hat{e}_t\right) =
\end{array}
\begin{array}{c}
\begin{array}{ccccccccc}
\text{FB} & \text{FP} & \text{FC} & \text{WB} & \text{WP} & \text{WC} & \text{RB} & \text{RP} & \text{RC}
\end{array}
\\
\left[\begin{array}{ccccccccc}
1.000 & & & & & & & & \\
-0.049 & 1.000 & & & & & & & \\
0.065 & 0.064 & 1.000 & & & & & & \\
0.572 & 0.027 & -0.011 & 1.00 & & & & & \\
-0.018 & 0.944 & 0.074 & 0.044 & 1.000 & & & & \\
0.048 & 0.062 & 0.883 & -0.059 & 0.056 & 1.000 & & & \\
0.109 & 0.097 & 0.085 & 0.071 & 0.075 & 0.036 & 1.000 & & \\
0.056 & 0.373 & 0.167 & 0.170 & 0.315 & 0.154 & 0.172 & 1.000 & \\
0.024 & 0.106 & 0.798 & -0.025 & 0.083 & 0.691 & 0.094 & 0.246 & 1.000
\end{array}\right]
\end{array}
\begin{array}{c}
\\
\text{FB} \\ \text{FP} \\ \text{FC} \\ \text{WB} \\ \text{WP} \\ \text{WC} \\ \text{RB} \\ \text{RP} \\ \text{RC}
\end{array}
$$

Figure 7. Correlation Matrix of the Innovations ($\hat{e}$) estimated from the ECM

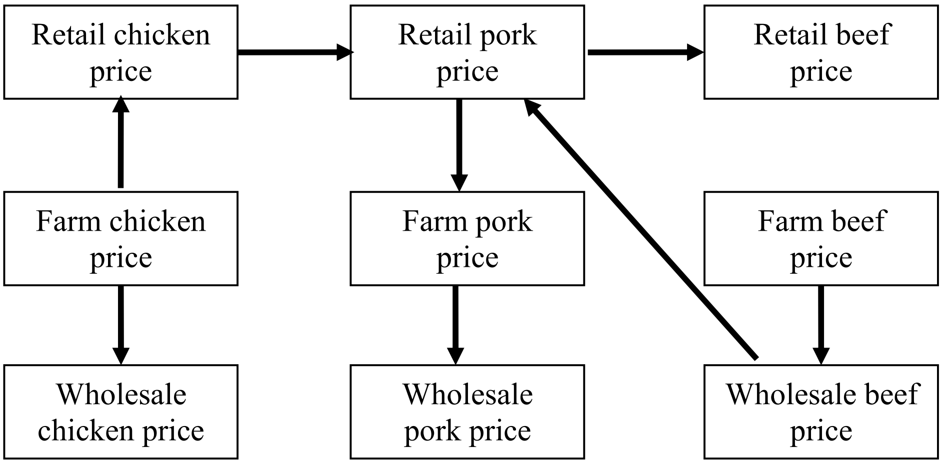
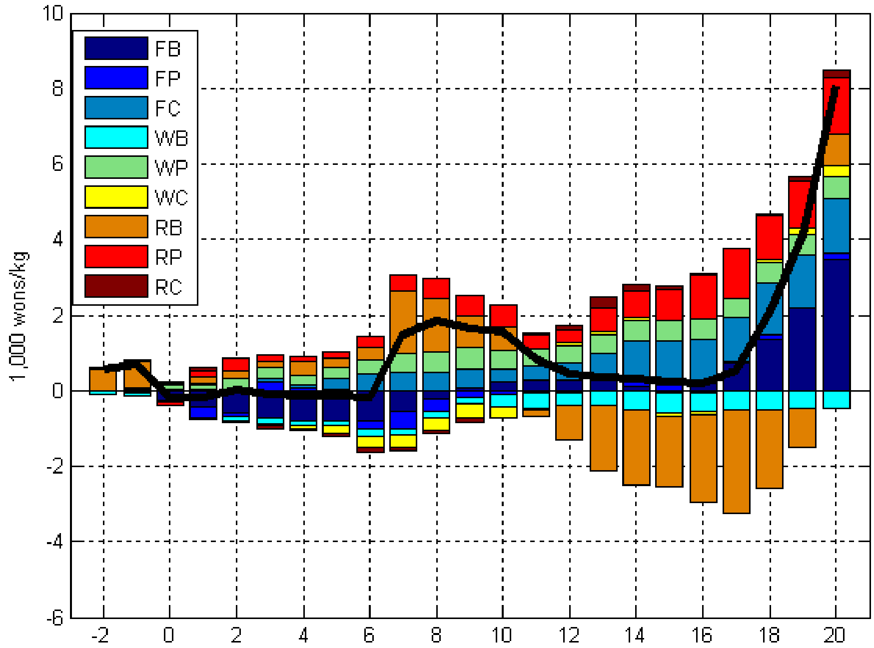
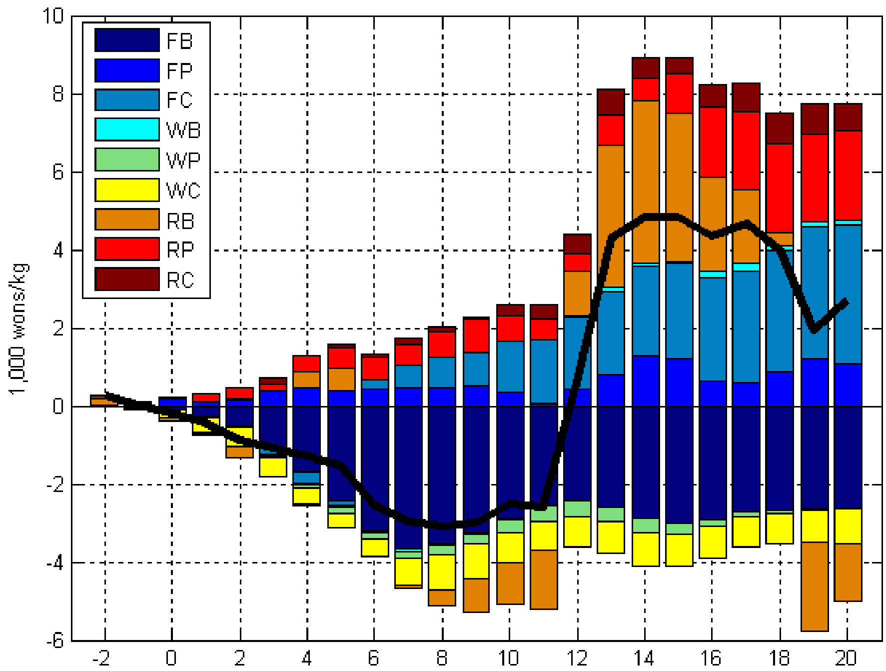


Figure 8. DAG results based on the GES Algorithm



(a) Responding to the 2000 FMD outbreak



(b) Responding to 2003 AI/BSE incidents

Figure 9. 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)