ECONOMIC ANALYSIS OF THE MEAT SUPPLY CHAIN

A Dissertation

by

MOON-SOO PARK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2008

Major Subject: Agricultural Economics

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Approved by:

Co-Chairs of Committee,	H. Alan Love
	Yanhong H. Jin
Committee Members,	David A. Bessler
	Steven Puller
Head of Department,	John P. Nichols

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ABSTRACT

Economic Analysis of the Meat Supply Chain. (May 2008)

Moon-Soo Park, B.S., Chonnam National University

Co-Chairs of Advisory Committee: Dr. H. Alan Love
Dr. Yanhong H. Jin

Recently, the meat supply chain has undergone a number of structural changes including increased concentration and a greater degree of quasi-vertical integration coordinated through contract procurement. The effects these changes have had on the meat supply chain, arranged as a complex array of producers, processors, distributors, and retailers, are not yet known. This study investigates the motives for, and consequences of, recent changes in the meat supply chain.

The first essay examines causality among variables in the U.S. cattle supply chain using temporal and contemporaneous causality methodologies. Tests for structural changes reveal a likely structural change between later 1996 and early 1997 that was likely induced by the turnaround of the U.S. cattle inventory accompanied with severe droughts in Midwest. Results suggest that overall temporal causalities in the U.S. cattle supply chain become weaker after the structural change, though relatively strong causalities are found in pre-break periods. In contrast, strong contemporaneous causal relationships are founded in post-break periods. One conclusion is that recent structural changes in the industry are resulting in more rapid transmission of information through the supply chain. Causal evidence also suggests that the direction of information

transmission has changed in recent times from moving generally downstream to moving generally upstream. This might be the result of increased concentration at the packer and retail levels giving rise to increased ability to “set” prices.

The second essay develops a theoretical model to investigate the dynamic effects of the contract procurement on packer competition in the spot market with general contract pricing scheme. Results indicate that packers have an incentive to consider the effects of spot market purchases on contract procurement even after accounting for hedonic characteristics of live cattle and risk aversion in cattle feeding operations.

The third essay investigates the impacts of domestic and overseas animal disease outbreaks on the Korean meat supply chain. Market impacts are investigated using both forecasts and historical decomposition of price innovations based on an error correction model (ECM) of the Korean meat sector. Results indicate that while the affected markets suffered significantly from the outbreaks, the impacts seem temporary and substitute meat markets benefited significantly.

To my wife and my family

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TABLE OF CONTENTS

LIST OF FIGURES

Page

Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

In this study, we examine the meat supply chain of two different markets including the U.S cattle supply chain and the Korean meat supply chain. Although geographically separated and distinguished by economic size, the fundamental market structures of both are similar and also they are vulnerable to similar external factors. Today's meat supply chain faces growing challenges—increasing operational complexity, new government regulations, consolidation within the industry, and food safety issues. Addressing how these issues are affecting the meat supply chain is important to market participants and may provide insights in to similar sectors elsewhere in the economy.

As an important value-generating industry, the transformation of U.S. cattle supply chain has enormous impacts on the U.S economy, especially on the food industry. In particular, concentration and consolidation through quasi-vertical integration has been a basic characteristic that has affected structural changes taking place in each stage of marketing and production through the supply chain. Consolidation allows increasing market efficiency as well as reducing transaction cost. However, it may facilitate market power exertion which can reduce market competitiveness. In the U.S. beef supply chain, quasi-vertical integration through the use of captive supply has raised concerns among livestock producers. Although the relationship between captive supply and fed cattle price has received considerable attention in previous studies, the causal relationships

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among prices and other variables reflecting market structure throughout the supply chain has barely received attention. Therefore, causal relationships among variables in U.S. cattle supply chain should be addressed. Understanding causal linkages among different segments of the U.S. cattle supply chain has rich policy implications for both regulators and economic participants in the supply chain.

Increasing use of captive supply contracts has made it difficult for fed cattle producers to understand contract prices and increasingly there is concern about the efficiency of price signals emerging from the spot market. Beef packers are rapidly switching from traditional spot procurement in fed cattle markets to contract procurement using contracts containing Top-of-the-Market-Pricing (TOMP) clauses where the base contract price is set it at the highest spot price. Possible reasons to use contracts in fed cattle market procurement are to manage risk and to improve quality. However, contract procurement may reduce competition in the fed cattle spot market, potentially leading to increased market power for packers. In practice, contract prices reflect both observed and unobserved hedonic characteristics of fed cattle and stochastic market related influences. Therefore, contract prices could deviate from the spot market prices. This complicates uncovering the effect of TOMP clauses on spot market price.

Another complicating factor is that packers repeatedly interact with each other both over time and across feedlots. Although there is no empirical evidence that meatpackers act as a collusive monopsony, packers may learn to coordinate their strategies in a dynamic setting and hence, compete less aggressively with each other in order to raise their profit over the level that could be attained in a static or finite setting. Thus, a model based on one-shot game framework may produce distorted results.

Concern of food safety due to animal disease has increased in all over the world since bovine spongiform encephalopathy (BSE) was discovered in UK in 1986. Animal disease outbreaks, especially those that could spread to humans, might alter the consumption pattern of the meat products as consumers lose confidence in food safety. Trade liberalization in recent years contributed to globalization of livestock industry. For example, the U.S., the largest producer of beef in the world, exports more than 10% of its beef production, with Japan, South Korea, Mexico, and Canada accounting for almost 90% of the export value in 2003. As such, outbreaks of animal diseases such as bovine spongiform encephalopathy (BSE), food-and-mouth disease (FMD), and avian influenza (AI) can have serious consequences for the livestock industry and the public health in both exporting and importing countries. In particular, Korea is import-dependent for its meat supply and traditionally has been one of the major export markets for U.S. beef, importing nearly 70% of its total beef consumption from the U.S. Therefore, animal disease outbreaks have been considered as a global public "good" emanating a negative externality that causes economic disruptions in the affected exporting country as well as importing countries.

Most previous research aside from the cases of Europe and the U.S. mainly focuses on animal disease outbreaks in Japan (Jin et al., 2003; McCluskey et al., 2005; Peterson and Chen, 2005; Saghaian et al., 2007). Only few researches have examined the response of the Korean meat market to food scares and econometric studies concerning the impact of food scare in Korea are hardly found.

Objective 1

The first objective of this study is to investigate causal relationships among variables in the U.S. cattle supply chain to enhance understanding of the U.S. cattle sector. Previous work has focused on the impact of captive supplies on fed cattle cash market prices. We take a broad approach, investigating the relationships among prices and selective sector driving variables throughout the supply chain. In particular, both Granger causality tests for temporal causality and graph-theoretical analysis for contemporaneous causality are employed for investigating causality in U.S. cattle supply chain. Tests for structural changes are conducted to ensure reliability of model results. Causal relations will be estimated to determine how the relationships among prices and diving variables may have changes for the pre- and post- break periods.

Objective 2

The second objective is to develop a dynamic game theoretic framework to investigate the incentives for, and the dynamic effects of, contract and spot market cattle procurement by packers. The U.S. beef supply chain has experienced increasing concentration at both the packer and grocery retail levels and increasing use of contracts to coordinate transactions between tiers throughout the vertical structure. Based upon this industry background, a stage-game is set up and solved that allows relations between contract and spot market price to be investigated. The model captures the impacts of captive supply, hedonic characteristics of fed cattle, and risk aversion among cattle producers. This applied theory model, while complex, should improve our understanding of how a number of complex factors interact to determine cattle prices.

Objective 3

The final objective is to 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. To identify and quantify the impacts of animal disease outbreaks on the Korean meat market we employ time series methods, mainly forecasting based on the error correction model (ECM) and historical decomposition of price innovations accompanied by directed acyclic graphs (DAGs) for contemporaneous causal ordering, 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.

Organization of the Study

This dissertation will consist of three autonomous essays. Each essay is self-contained including introduction, methodology and conclusion, and addresses one of the three objectives. Chapter II contains an article title “Causality and Structural Changes in the U.S Cattle Supply Chain”. This chapter fulfills the goals described under the first objective. Chapter III develops model to fulfill the goals the described in the second objective in an article titled “Contract Pricing and Packer Competition in Fed Cattle Market.” Chapter IV consists of an article titled “The Impacts of the Animal Disease Crises on the Korean Meat Market” as described in the third objective. Finally, Chapter V contains a collective discussion of the results and concluding comments. A cumulative set of reference and appendices follow Chapter V.

CHAPTER II

CAUSALITY AND STRUCTURAL CHANGES IN THE U.S. CATTLE SUPPLY CHAIN

The U.S. beef supply chain experienced a rapid transformation in recent years. The industry has become more concentrated at both the processor and retail levels. In addition, the beef processing industry is making increased use of contract production at the farm level (GIPSA 2002) and antidotal evidence suggests increased use of contracts to coordinate exchange between processors and retailers. Taken together, these changes suggest that the beef supply chain has become more tightly coordinated through contracts. Whether this has improved vertical coordination among the various tiers in the supply chain is an important but difficult issue to analyze. However, it is certainly the case that understanding causal linkages along the supply chain and how they might have changed through time has important implications for policy makers, for economic agents within supply chain, and for consumers.

GIPSA defines captive supply as cattle owned or fed by packers or cattle procured from independent producers through forward contracts and marketing agreements so that cattle that are committed to a packer more than 14 days prior to slaughter (GIPSA 2002). The increasing use of captive supply along with high concentration among packers has raised concern about competitiveness and possible market manipulations by packers in spot market procurement (Love and Burton 1999; Xia and Sexton 2004). The relationship between captive supply and fed cattle spot price has received considerable attention. Contract prices for fed cattle are based on cash price at the time of slaughter and producers believe that processors may use contracts to reduce volume on the cash market, thereby lowering both cash and contract price (Xia and Sexton, 2004). However, results from previous studies find that the relationship between captive supply and fed cattle spot prices are mixed (Schroeder et al., 1993; Parcell, Schroeder, and Dhuyvetter, 1997; Ward, et al., 1998). Feuz et al. (2002) suggest that captive supply reduces transaction costs and market risk and, therefore, enhances efficiency and market competitiveness. Whereas, Conner et al. (2004) argue that captive supply may decrease fed cattle spot prices, soften competition, disfavor market access by small cattle producers, and increase market power of packers. However, previous studies do not say anything about causal direction between two variables even though the model may have a natural or implicit causal direction. The causal relationships among the U.S. beef supply chain remain as an important and challenging issue.

In this article, we investigate causalities among variables in the U.S. beef supply chain. While previous work has focused on the impact of captive supplies on fed cattle cash market prices, we take a broad approach investigating relationships among prices and selective sector driving variables throughout the supply chain. Both Granger causality tests for temporal causality and graph-theoretical analysis for contemporaneous causality are employed. Causality tests based upon forecast performance or predictive ability are widely implemented by in-sample Granger causality tests. However, Ashley et al. (1980) suggest that following Granger (1969) causality tests should be based on out-of-sample testing. Ashley et al. (1980) state ". . . a sound and natural approach to such [Granger causality] tests must rely on the out-of-sample forecasting performance of models relating the original series of interest." There is an emerging literature advocating out-of-sample Granger causality tests (McCracken, 1999; Amato and Swanson, 2001; Clark and McCracken, 2001; Corradi and Swanson, 2002). Swanson and Granger (1997), who first introduce graphical methods into contemporaneous causal ordering of VAR models, argue that contemporaneous causal ordering can be complementary to Granger causality when there is temporal aggregation. Several studies employ DAGs to uncover the contemporaneous causal relations between innovations of VAR-type models (Bessler and Lee 2002).

We also test for structural changes in the relationships among variables at different tiers of the supply chain and examine whether and how causalities change when a structural change occurs. Several events that may have changed relationships in the beef supply chain are of particular interest. The 1996-1997 grain shock and the turnaround of the U.S. cattle cycle may affect cattle market structure (Mathews et al., 1999). The Livestock Mandatory Price Reporting (LMPR) Act of 1999 became effective on April 2nd, 2001 and expired in October 1st, 2005. The Act required meat packers to report both price and quantity information on all cattle purchased, including cattle purchased through contracts, to the Agricultural Marketing Services (AMS) of USDA (Njoroge et al., 2007). It mitigated what cattle producers perceived as packers' unfair advantage of unilateral access to contract price information (Njoroge et al., 2007). The reported occurrences of Bovine Spongiform Encephalopathy (BSE) infected cattle in the in US beef supply in December 2003 likely affected domestic beef demand and resulted in the halting of US beef exports to many countries (Mattson and Koo, 2007). Our results show that the 1996 grain shock caused a significant structural change while the BSE discovery and the LMPR act had minor changes.

The article is organized into five additional sections. The next section provides an overview of the U.S. beef supply chain and data descriptions. The section following describes the empirical methodology, including time-varying cointegration, out-of-sample Granger causality tests, and directed acyclic graphs. The article then presents empirical results and provides conclusions and policy implications.

Overview of the U.S. Beef Supply Chain and Data Description

The U.S. beef supply chain is characterized by multiple production stages with rearing and weaning taking place in cow-calf operations sometimes including background operations, feeding to market weight by feedlots, slaughtering and fabricating by packers, and finally merchandising by retailers to consumers. This supply chain is illustrated in Figure 2.1. Cow-calf and background operations are first-stage producers providing feeder steers and heifers weighing more than 500 pounds. Feedlots (feeding operations) purchase feeder cattle from cow-calf operations and feed the animals with high-energy rations to finish them as fed cattle weighing approximately 1200 pounds. These fed cattle are purchased by beef packers. Beef packers slaughter and fabricate the finished fed cattle in their packing plants, and produce boxed (or wholesale) beef as their final output. Retailers including supermarkets, grocery stores, fast-food outlets, and restaurants are placed on the top of the supply chain. They sell beef to consumers. We use monthly data for nine variables representing different stages of the U.S. beef supply chain. Data are from January 1988 to August 2005, and include captive supply, cattle inventory, feeder cattle prices, fed cattle spot prices, boxed beef prices, retail beef prices, fed cattle futures prices, corn prices, and the packer Herfindahl-Hirschman Index. All variables except captive supply and fed cattle futures prices are collected from the Red Meat Yearbook published by Economic Research Service (ERS) of USDA.

Captive supply (CAPT), which is measured by the percentage of the total slaughter procured through long-term contracts by the four largest packing firms, is obtained from GIPSA. It is used to represent the degree of quasi-vertical integration in the cattle industry. Based on semi-annual cattle inventory data published by ERS in January and July we construct monthly cattle inventory (INVT) by subtracting monthly cattle slaughter from the previous cattle inventory and adding the monthly calf crop. Cattle inventory provides information on current and future beef production. Although the cyclical influence of cattle inventory is a primary factor determining beef supply that affects all the live cattle stages in the supply chain, it also has a large effect on overall cattle industry since the industry itself is cyclical in nature. We use feeder steer price (Oklahoma City, 750-800 lb, medium #1) to represent feeder cattle prices (FEEP), wholesale boxed beef cut-out value (Choice 1-3, Central U.S., 600-750 lbs) for boxed beef prices (BOXP), USDA all-fresh retail beef price from the Cattle Fax for retail beef prices (REBP), and Corn #2 Yellow, Central Illinois for feed corn prices (CORP). Fed cattle spot price (FEDP) is a weighted price index using a Tornquist index based on prices and quantities of steers and heifers (Choice 2-4, Nebraska, 1,100-1,300 lbs). Fed cattle constitute a major input to the packer’s production process, accounting for the most of the production costs. Fed cattle futures prices (FUTP) traded in Chicago Mercantile Exchange (CME) are obtained from the DataStream, an electronic database system providing historical financial data sets. The Herfindahl-Hirschman Index (HHI), calculated as the sum of the squared market shares of individual firms reported by GIPSA is used as a measure for market concentration. Industries with an HHI below 1000 are classified as unconcentrated, between 1000 and 1800 moderately concentrated, and above 1800 highly concentrated. Figure 2.2 plots these nine variables during the study period (1988:1-2005:8). For the empirical analysis, we conduct logarithmic transformation of all the nine series.

Econometric Methodologies

Complementary tests for both temporal and contemporaneous causality are used to gain understanding of the U.S. beef supply chain. We conduct out-of-sample Granger causality tests for temporal causality and directed acyclic graphs (DAGs) to uncover contemporaneous causality. Causal relationships in the U.S. beef supply chain may change if there is a structural change. Therefore, tests for structural change are warranted before applying causality tests. We employ time-varying cointegration methods to test for structural changes and then conduct causality tests before and after any structural change. The detailed discussions of these methodologies are provided the rest of this section.

Time-Varying Cointegration Methods to Test for Structural Changes

Time-varying cointegration methods that assume parameters vary over time have been mainly employed in the financial economics literature (Rangivid and Sörenson, 2002; Brada et al., 2005; Yang, 2006). Based upon Johansen's (1991) maximum likelihood estimation method we utilize both recursive and rolling time-varying cointegration methods.

Let X_t denote a $p \times 1$ random vector representing *p* non-stationary time series. The data generating process of X_t can be written by a vector error correction model (VECM) when *p* time series are cointegrated:

(2.1) $$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu + \varepsilon_t \quad \text{for } t = 1, \ldots, T,$$

where Δ is a first-order difference operator such that $\Delta X_t = X_t - X_{t-1}$, $\Pi = \alpha\beta'$ is a $p \times p$ coefficient matrix indicating long-run relationships among variables, and Γ_i is also a $p \times p$ coefficient matrix measuring the short-run effect of ΔX_{t-i} on ΔX_t. The rank of Π determines the cointegration rank, *r*. Equation (2.1) can be re-written in a matrix format,

(2.2) $$Z_{0t} = \alpha\beta' Z_{1t} + \Gamma Z_{2t} + \mu + \varepsilon_t \quad \text{for } t = 1, \ldots, T,$$

where $Z_{0t} = \Delta X_t$, $Z_{1t} = X_{t-1}$, $Z_{2t} = \left[\Delta X'_{t-1}, \ldots, \Delta X'_{t-k+1}\right]$ and $\Gamma = \left[\Gamma_1, \ldots\ldots, \Gamma_{k-1}\right]$. The maximum likelihood estimation of equation (2.2) consists of a reduced rank regression of Z_{0t} on Z_{1t} conditional on Z_{2t}. Let $R_{0t}^{(n)}$ and $R_{1t}^{(n)}$ denote residuals from the regression of Z_{0t} and Z_{1t} on Z_{2t}, and $R_{\varepsilon t}^{(n)}$ denote the corresponding residual errors, where the superscript n denotes number of observations used for the estimation. Hence, $R_{0t}^{(n)}$, $R_{1t}^{(n)}$, and $R_{\varepsilon t}^{(n)}$ are $R_{0t}^{(n)} = Z_{0t} - M_{02}^{(n)}\left(M_{22}^{(n)}\right)^{-1} Z_{2t}$, $R_{1t}^{(n)} = Z_{1t} - M_{12}^{(n)}\left(M_{22}^{(n)}\right)^{-1} Z_{2t}$, and

$R_{\varepsilon t}^{(n)} = \varepsilon_t - M_{\varepsilon 2}^{(n)}\left(M_{22}^{(n)}\right)^{-1} Z_{2t}$,

for $t = 1, \ldots, n$, where $M_{ij} = \sum_{s=1}^{n} Z_{it} Z_{jt}^{'}$ and $M_{\varepsilon j} = \sum_{s=1}^{n} \varepsilon_t Z_{jt}^{'}$ $(i, j = 0, 1, 2)$. The remaining analysis is based on the following regression equation where the parameter Γ vector has been filtered out:

(2.3) $\quad R_{0t}^{(n)} = \alpha\beta^{'} R_{1t}^{(n)} + R_{\varepsilon t}^{(n)} \qquad$ for $t = 1, \ldots, n$.

Equation (2.3) is estimated using both rolling and recursive methods. Post estimation we use trace tests to determine the rank of the time-varying cointegration vectors. Both recursive and rolling estimations start with a base sample period n_0 for $1 < n_0 \le T$. Let's consider an example of 60-month base sample ($n_0 = 60$). The recursive estimates are obtained by adding one additional observation to each estimate. That is, the first 60 observations are used to obtain the first trace test statistic; the first 61 observations are used for the next trace statistic, and so on, till the first T-1 observations are used to obtain the last trace statistic. In contrast, the rolling estimates use a constant rolling window size of 60-month observations. The first 60 observations are used to obtain the first trace test statistic, the 2nd to the 61st observations are used to obtain the second trace statistic, and so on till the last observation is used.

Based on equation (2.3), we obtain eigenvalues $1 > \hat{\lambda}_1^n > \ldots > \hat{\lambda}_p^n > 0$ and $\hat{\lambda}_{p+1}^n = 0$, and eigenvectors $\hat{V} = (\hat{v}_1^n, \ldots, \hat{v}_p^n)$ that are the solutions for the eigenvalue systems:

(2.4) $\left|\lambda S_{11}^{n} - S_{10}^{n}\left(S_{00}^{n}\right)^{-1} S_{01}^{n}\right| = 0$,

where $S_{ij}^{n} = \frac{1}{n}\sum_{s=1}^{n} R_{is}^{(n)} R_{js}^{(n)'}$ for i, j = 0, 1 is residual product matrices corrected for Z_{2t} based on each sub-sample. The eigenvalues of equation (2.4) are used to form tests for stability of parameter estimates (See Hansen and Johansen (1999) for details). We use the *p-r* smallest non-zero eigenvalues, $\hat{\lambda}_{-}^{n} = (\hat{\lambda}_{r+1}^{n}, \ldots, \hat{\lambda}_{p}^{n})$ corresponding to non-stationary relations to form trace tests for the rank of the time-varying cointegration vectors. Let τ_{p-r} define the trace test statistics to test for the null hypothesis of rank *r*:

(2.5) $\tau_{p-r} = -2\ln Q(H_r \mid H_p) = -n\sum_{i=r+1}^{p} \ln(1-\hat{\lambda}_{i}^{n})$,

where the hypotheses H_p and H_r imply there exists either no unit root or *p-r* unit roots and *r* cointegration rank, respectively. The null hypothesis of *r* cointegration rank is rejected at the 5% significance level if the value of the normalized trace statistic is greater than one. Since causal relationships in the U.S. cattle industry may change if there is any structural change, we conduct causality tests before and after the structural change.

Modeling Causalities

Causality that reflects asymmetric relations between two variables differs from correlation through the process of identification (Moneta, 2005). Although there is no unique definition of causality (see Moneta, 2005 for details), the identification problem must be solved before investigating causalities. There are two competing approaches to resolve the identification problem, the deductive structuralist approach represented by Cowles Commission (Simon, 1953) and the inductive probabilistic approach embodied in Grangers' causality tests (Granger, 1969) and Sim's vector autoregression model (Sims, 1980).

The Cowles Commission argues that causality is derived based on *a priori* economic theory. The inductive probabilistic approach regards economic theory as an unreliable source of causal relation and explores the possibility of inferring causes based on statistical properties of the data without *a priori* theory restriction. Expecting that the past and present values of x_t contribute to predicting y_t, Granger (1969) defines x_t Granger-causes y_t if and only if

$P(y_t \mid y_{t-1}, y_{t-2}, \ldots, x_{t-1}, x_{t-2}, \ldots, \Theta) \neq P(y_t \mid y_{t-1}, y_{t-2}, \ldots, \Theta)$, where Θ is the information set. Granger causality may be the most influential approach to identify causality in economics. It is based on lag relations between observations and therefore has little to say about contemporaneous causation.

Sims (1980) claims that the theoretical restrictions used by the Cowles Commission for the identification are not well-grounded and the structural equations are in principle not identifiable. VAR models proposed by Sims, however, also require model restrictions for policy interpretations because an estimated VAR model following a reduced form cannot be used to infer causal relations. In particular, innovations computed from reduced VAR models cannot be isolated since a particular innovation is in general correlated with other unorthogonalized innovations. Sims (1980) proposes Choleski factorization and incorporates it into VAR models (we call structural VAR models) to identify the contemporaneous effects of economic shocks. But the Choleski factorization, which allows researchers to arbitrarily choose one case among various possible causal stories, has received severe criticisms. Demiralp and Hoover (2003) argue that the majority of the literature that uses structural VAR models to identify contemporaneous causal structure among variables is conceptually consistent with the Cowles methodology that derives such restrictions from economic theory or from *a priori* knowledge.

To overcome the arbitrariness resulting from Choleski factorization in the Sims' structural VAR model, we employ DAGs to uncover contemporaneous causality. Developed by Pearl (2000) and Spirtes et al (2000) DAGs utilize conditional probabilities and graph theory (Swanson and Granger, 1997; Bessler and Lee, 2002; and Demiralp and Hoover, 2003), which is consistent with the "inductive probabilistic approach" suggested by Granger.

(a) Out-of-Sample Granger Causality Tests for Temporal Causality

The majority of previous studies on Granger causality focuses on in-sample predictive tests and is mainly based on the standard in-sample F or Wald tests. However, in-sample Granger causality tests using all observations for forecasting, risk over-fitting the data. Over-fitting causes spurious prediction and biased test results. To overcome the over-fitting problem, we follow Amato and Swanson (2001) and implement out-of-sample Granger causality tests.

To implement out-of-sample Granger causality tests in a multivariate system, we first examine whether the inclusion of series X_{jt} facilitates obtaining a better prediction of series X_{it} (i = CAPT, INVT, FEEP, FEDP, BOXP, REBP, FUTP, CORP, HHI, but $i \neq j$) given other series. We construct two VECMs specifications based on equation (2.1): the unrestricted full model includes all nine variables, and the restricted models exclude one specific variable from the unrestricted full model. We rewrite equation (2.1) as:

$$(2.6) \qquad \Delta X_t^m = \Pi^m X_{t-1}^m + \sum_{i=1}^{k-1} \Gamma_i^m \Delta X_{t-i}^m + \mu^m + \varepsilon_t^m \text{ for } t = 1, \ldots, T,$$

where m indicates the unrestricted ($m = u$) and restricted ($m = r$) models, X_t^u is a 9×1 vector for the unrestricted model, X_t^r is a 8×1 vector excluding X_{jt} for the restricted model, and ε_t^m is a multivariate *iid* sequence with mean zero and covariance matrix Σ^m.

The out-of-sample Granger causality test is conducted using a three-stage procedure with recursive estimation. In the first stage, the first R observations are used to forecast $X_{i,R+1}^m$, the first R+1 observations are used to forecast $X_{i,R+2}^m$, and so on until the first T-1 observations are used to forecast $X_{i,T}^m$. Consequently, we have a total of T - R one-step-ahead forecasts $\hat{X}_{i,t}^u$ and $\hat{X}_{i,t}^r$ for $t = R+1, R+2, \cdots, T$ based on the unrestricted and restricted models. In the second stage, we calculate the unrestricted forecast error ($e_{it}^u = X_{it} - \hat{X}_{it}^u$) and the restricted forecast error ($e_{it}^r = X_{it} - \hat{X}_{it}^r$), where X_{it} is the actual series. We say that X_{jt} Granger causes X_{it} if e_{it}^u is smaller than e_{it}^r or if the unrestricted full model including X_{jt} results in more accurate forecasts than the restricted model. In the final stage, we examine whether there exists a statistically significant difference between the unrestricted and restricted models in terms of their predictive accuracy. Based on the mean squared forecasting errors criterion suggested by Amato and Swanson (2001), we employ the modified Diebold-Mariano (DM) test (Harvey et al., 1997) for equal forecasting performance in which the null hypothesis is $H_0 : d_t = e_{ut}^2 - e_{rt}^2$. The corresponding DM test statistic is

(2.7) $$DM = \left(\hat{V}(\bar{d})\right)^{-0.5} \bar{d} ,$$

where $\bar{d}$ is the sample mean of d_t, $\hat{V}(\bar{d})$ is the Newey–West heteroskedacity and autocorrelation consistent estimator of the sample variance of d_t. Since the distribution under the null hypothesis is nonstandard, we use the simulated critical value developed by Clark and McCracken (2001) for DM tests.

The Granger causality test might be spoiled by temporal aggregation. Temporal aggregation occurs when the frequency of observations, i.e., sampling interval, usually differs from the natural frequency of the underlying time series. The presence of temporal aggregation may lead to misleading inference of Granger causality. In particular, Tiao (1999) summarized the distortion due to temporal aggregation as, "…the causality issue is muddled once the data are aggregated. The problem is that if the data are observed at intervals when the dynamics are not working properly, then we may not get any kind of causality." In the spirit of Granger causality, the causal event is observed ahead of the effect when we assume the cause and effect are ordered in time and the sampling frequency is sufficient to discern the cause and the effect. There should be no contemporaneous relationship between the cause and effect if the sampling frequency is observed at the natural frequency (Granger, 1988). In reality, however, it is rare to get a data set that have no or very small temporal aggregation bias with exception of high frequency financial data. Hence, contemporaneous causality observed under a particular time interval may result from temporal aggregation.[1] Therefore, it is useful to link the concept of Granger causality at the natural frequency with contemporaneous causality for the time aggregated process (Swanson and Granger, 1997; Breitung and Swanson, 2002).

(b) Contemporaneous Causality Test Using DAGs

DAGs are pictures using arrows and vertices (variables) to represent the contemporaneous causal flow among or between a set of variables based on observed correlation and partial correlations (Pearl, 2000). Mathematically, DAGs can be used to represent conditional independence as implied by the recursive product decomposition:

$$\text{(2.8)} \qquad \Pr(v_1, v_2, v_3, ..., v_n) = \prod_{i=1}^{n} \Pr(v_i \mid pa_i)$$

where Pr is the probability of vertices $v_1, v_2, v_3, ... v_n$ and pa_i is the realization of some subset of the variables that precede v_i in order ($v_1, v_2, v_3, ... v_n$).

In DAGs, searching for conditional independence and/or dependence is a starting point to examine the indecisive causal relationship among variables. Pearl (2000) proposes "d-separation" as a graphical characterization of conditional independence. Two variables are said to be d-separated if the information flow between them is blocked by a third variable. The notion of d-separation is more clearly conceptualized by "causal

[1] Granger (1988) suggests that missing variable also can be a source of contemporaneous causality under time interval. However, it is hard to identify what missing variables exist.

chain," "causal forks", and "causal inverted forks." A case of causal chain $A \rightarrow B \rightarrow C$ (that is, *A* causes *B* and *B* causes *C*) suggests that *A* and *C* are dependent (d-connected) but *A* and *C* are independent (d-separated) conditional on *B* since *B* opens up the information flow between *A* and *C*. In the case of causal forks, $A \leftarrow B \rightarrow C$, *A* and *C* are dependent but *A* and *C* are independent conditional on *B* as a common cause. In the case of inverted forks, $A \rightarrow B \leftarrow C$, *A* and *C* are independent since the information on *A* cannot pass through to *C* by *B* (i.e., collider), but *A* and *C* are dependent (d-connected) conditional on *B*. Two DAGs are distributionally equivalent if they are generated by same probability distribution and are independence equivalent if they have identical independence constraints.

We use the greedy equivalent search (GES) algorithm to generate DAGs (Chickering, 2002).[2] The algorithm starts with an equivalence class with no dependencies among variables following the Bayesian scoring criterion of Schwarz loss:

(2.9) $$\mathrm{S}(\mathrm{G},\mathrm{D}) = \ln P(D \mid \hat{\theta}, G^k) - \frac{h}{2}\ln T\ ,$$

where *P* is the probability distribution, $\hat{\theta}$ is the maximum-likelihood estimate of the unknown parameters, *h* is the number of free parameters (not equal to zero) of DAG *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 $\frac{h}{2}\ln T$. The GES algorithm suggests a move in the

[2] GES algorithm has several advantages over PC algorithm as an alternative algorithm. GES Algorithm does not require as strong assumptions as PC Algorithm (Causal sufficiency, Markov condition, Faithfulness). Also an appropriate significance level is not required to GES algorithm.

direction that increases the Bayesian score the most until no such move increases the score. Formally, the GES algorithm is a two-phase stepwise search algorithm that consists of both forward equivalence class search for addition of single edges in the first phase and backward equivalence class search for deletion of single edges in the second phase. Through forward equivalence search for sequentially single edge additions, one equivalence class that has the highest increasing score among all possible equivalence classes is chosen for the next phase. Once a local maximum is determined in the first phase, we conduct backward equivalence search to sequentially delete a single edge in the second phase and compare the scores of DAG in equivalence classes repeatedly until a local maximum is reached. The search algorithm is terminated if the algorithm reaches a local maximum in the second phase. More details on the algorithms are in Chickering (2002, p. 520-24).

Empirical Results

This section discusses the empirical results for structural change and causality.

Results of the Structural Change Analysis

Augmented Dickey Fuller (ADF) test results suggest that all series are non-stationary in levels (logarithms). The optimal lag length is two based on Hanna and Quinn's (HQ) metrics for the VAR system. We employ both rolling and recursive cointegration methods to determine possible structural changes in the U.S cattle industry based on results of the time-varying trace tests. Generally, the sources of structural change in agricultural commodities come from policy change, supply shocks due to weather abnormalities or disease outbreaks, and demand shocks like unexpected change of consumer preference.

As shown in Figure 2.3, the normalized rolling trace test results suggest the presence of time-varying cointegration relationships among variables in the supply chain. Obviously, the null hypotheses of no cointegration ($r = 0$) and one cointegration vector ($r \leq 1$) are rejected over the whole sample periods since all the trace test statistics are greater than one. Based on trace test results for the null hypotheses of two and three cointegration vectors ($r \leq 2$ and $r \leq 3$), minor regime changes in early 2001 and 2003 are detected. We speculate two events contribute to the instability of the cointegration, the Livestock Mandatory Price Reporting Act (LMPR) effective in April 2001 to stimulate competition in livestock markets including fed cattle market, and the BSE discovered in December 2003 in the U.S.

The most striking evidence for instability of cointegration relationships detected in the null hypothesis of three cointegrating vectors ($r \leq 3$) suggests a remarkable structural change between late 1996 and early 1997. Results suggest that four cointegration vectors exist prior to early 1997 while three cointegration vectors exist in most time intervals post early 1997. The regime change between late 1996 and early 1997 coincides with a turnaround of the U.S. cattle production cycle. The U.S. cattle production cycle typically occurs every 10 to 12 years, which consists of six to seven years of expanding, one to two years of consolidation, and three to four years of declining before the next cycle begins (Mundlack and Huang 1996). The U.S cattle cycle experienced a contraction phase after the peak of cattle inventory in January 1996 (103.5 million head).[3] Along with the cattle cycle, a strong inverse beef price cycle was found in the same period and the price spread between feeder calves, feeder cattle, and slaughter cattle widened after 1996 (Hughes, 2002). The cattle cycle can greatly contribute to the transformation of market structure (Mathews et al., 1999). Grain shocks caused by a Midwestern draught between late 1995 and early 1996 may have amplified the cattle-cycle related market influences. The severe draught caused a remarkably high spike in corn price in 1996, which clearly affected profits throughout the beef supply chain.

Figure 2.4 illustrates the results of the recursive cointegration tests. We reject the null hypotheses of zero, at most one, and at most two cointegration vectors. We fail to reject the null hypothesis of $r \leq 3$ between late 1995 to early 1997, but reject the null hypothesis of $r \leq 4$ since early 2002. Two regime changes were suggested, one between late 1995 and early 1997 that coincided with the grain price shock and the turnaround of cattle inventory cycle and another one in early 2002 that was likely induced by the LMPR Act.

Based on results of the time-varying trace tests and our knowledge of historical events in the U.S. beef supply chain, we argue there were at least two regime changes, one corresponding to the 1996 grain shock and the turnaround of the U.S. cattle cycle and another one induced by the LMPR Act that became effective in 2001. However, we do not have sufficiently long series to analyze the post LMPR periods. Therefore, we

[3] USDA reports that cattle inventory decreased to 94.9 million head in January 2004 (cyclical low), but it has been expanded since 2005 (94.9, 95.4, and 96.7 million head in January 2005, 2006, and 2007).

divide the entire sample period into two sub-periods according to the regime change between late 1996 and early 1997: pre-break periods (1988:1–1996:10) and post-break periods (1997:3–2005:8). We exclude the 4-month interval (1996:12–1997:2) from the analysis as transition periods, since the contemporaneous causal orderings are sensitive to including these periods.

To validate the structural change, we conduct a recursive innovative accounting analysis and statistical tests for the homogeneity of two variance matrices and correlation matrices in the pre- and post-break periods

(a) Recursive Innovative Accounting Analysis

If there is a structural change, we should expect changes in recursive innovative accounting consisting of forecast error variance decompositions and impulse response functions after the structural break. Due to space limitation, we only present results of the impacts of captive supply and cattle inventory on spot market prices (feeder cattle price, fed cattle price, boxed beef price, and retail beef price) at 12-month or 24-month horizons in Figures 2.5 and 2.6.

Results illustrated in Figure 2.5 show: (i) the influence of captive supply on forecast error variance of feeder cattle price is generally weaker in the post-break periods than in the pre-break periods; (ii) the effect of captive supply on forecast error variance of fed cattle price becomes stronger over time; and (iii) the influence of captive supply on the forecast error variance of boxed beef and retail beef prices increases sharply after mid

1999.[4] Figure 2.5 suggests a dramatic decrease in the contribution of cattle inventory to forecast error variance of cattle and beef prices around 1996 but a reversal in 2001 so that after 2002 cattle inventory increases forecast error variance of cattle and beef prices. Figure 2.6 plots the orthogonalized impulse response function of four spot market prices responding to captive supply and cattle inventory, respectively. Results in Figure 2.6 show that an increase in captive supply decreases the spot market prices in the majority of the pre-break periods. However, starting in 1999, an increase in captive supply appears to increase cattle and beef prices. Also Figure 2.6 show that an increase in cattle inventory immediately decreases all four prices. Furthermore, the biggest price drops appear when the structural break occurred in 1996-1997. Overall, the comparison of innovation accounting between the before- and after-break periods supports the 1996-1997 structural change.

(b) Box-M and Jennrich Tests for the Homogeneity of Matrices

Based on estimated VECMs in the pre- and post-break periods, we obtain two covariance matrices of contemporaneous innovations, Ω_1 and Ω_2, as well as two correlation matrices, Σ_1 and Σ_2 (see Table 2.1). If there is a structural change, the two covariance matrices or two correlation matrices should statistically differ from each other. We employ both the Box-M (Box 1949) for the equality of the two covariance matrices and the Jennrich test (1970) for the equality of the two correlation matrices.

[4] Since 1999, beef demand has been strong and is improving. Demand has allowed record levels of beef production to continue moving through the system without further damage to the market value of cattle. With record retail price levels being set in 2001 and the increase in the retail beef demand index over the same period, there is plenty of evidence that beef demand has indeed improved.

Based on the sample covariance matrices (Ω_1 and Ω_2) we define the population covariance matrix by $\Omega = \sum_{i=1}^{2} n_i \Omega_i \Big/ n$, where n_i is number of observations to derive sample covariance matrix Ω_i, and *n* is the number of the entire sample ($n = n_1 + n_2$). As suggested by Mardia et al. (1979), when the sample size is small, the Box-M test statistic for the homogeneity of two covariance matrices is $M = \gamma \sum_{i=1}^{2} (n_i - 1) \log \left| \frac{\Omega_u}{\Omega_{ui}} \right|$ where

$\Omega_u = \frac{n}{n-2}\Omega$, $\Omega_{ui} = \frac{n_i}{n_i - 2}\Omega_i$, and $\gamma = 1 - \frac{2s^2 + 3s - 1}{6(s+1)}\left(\sum \frac{1}{n_i - 1} - \frac{1}{n-2}\right)$, and *s* is the dimension of the covariance matrix. The Box-M test statistic is asymptotically distributed as a chi-square distribution with the degree of freedom $s(s + 1)/2$. However, Box-M test is not adapted for testing the equality of two correlation matrices.

Jennrich (1970) proposed a chi-square test for the homogeneity of covariance as well as correlation matrices. The Jennrich test statistic for the homogeneity of two correlation matrices is $\frac{1}{2} tr(Z^2)$ where $tr(\cdot)$ is a trace operator, $Z = c^{1/2}\overline{\Sigma}^{-1}(\Sigma_1 - \Sigma_2)$,

$c = n_1 n_2 / (n_1 + n_2)$, and $\overline{\Sigma} = (n_1\Sigma_1 + n_2\Sigma_2)/(n_1 + n_2)$. The Jennrich test statistic is asymptotically distributed as a chi-square distribution with the degree of freedom $s(s - 1)/2$.

We have $s = 9$, $n_1 = 106$, and $n_1 = 102$. The statistic for the Box-M test (262.36) exceeds the critical value ($\chi^2(45) = 71.17$), and the statistic for the Jennrich test (135.44) also exceeds the critical value ($\chi^2(36) = 61.58$) at the 1% significance level.

Hence, we reject the null hypothesis and conclude that the two variance matrices or the two correlation matrices of contemporaneous innovations differ from each other. Both the Box-M and Jennrich tests support the structural change.

Results of Causality Tests

Before conducting VECM estimation we need to determine the optimal lag length (*k*) and the rank of the cointegrating vectors (*r*). To validate the results, we use both the information criterion and trace tests to determine *k* and *r* sequentially and the model selection method based on information criteria to jointly determine *k* and *r*. The model selection method was first proposed by Phillips (1996) to jointly determine *k* and *r*. Wang and Bessler (2005) provide simulation evidence that shows model selection methods based on information criterion give at least as good fit as conventional Johansen system-based LR tests. Baltagi and Wang (2007) find model selection methods produce the same results as system-based LR tests in 70% of 165 published data sets. The empirical results based on both methods are consistent -- the optimal lag length is two and the rank of cointegrating vectors is four in both pre and post-break periods. In the rest of this section, we present the causality results.

(a) Results of Granger Temporal Causality

To test for temporal causality using out-of-sample Granger tests, we construct one-step-ahead out-of-sample forecasts based on both the unrestricted and restricted VECMs formalized in equation (2.6) and compare mean squared forecast errors (MSFEs) between the unrestricted and restricted VECMs.

The unrestricted full model, including all nine variables with four cointegrating vectors, is estimated using observations from the first 60 monthly observations (1989:1–1993:12) to obtain one-step-ahead forecasts for 1994:1 of the nine series. The model is then re-estimated using the first 61 observations (1989:1–1994:1) to obtain the one-step-ahead forecasts for 1994:2 of the nine series. This procedure continues till the entire observations of the pre-break period are exhausted. Consequently, we obtain 34 one-step-ahead out-of-sample forecasts (1994:1-1996:10) for the unrestricted full model and nine forecast error series with dimension of 34-by-1 for the unrestricted model. The trace test results show that the cointegration rank is four for the restricted models excluding captive supply, feeder cattle price, boxed beef price, fed cattle futures price, corn price, and Herfindahl-Hirschman index, respectively. The rank is three in the restricted models excluding cattle inventory, fed cattle spot price, and retail beef price, respectively. Similarly, we obtain recursive estimates of the restricted VECM model using the first 60 monthly observations as a base sample. Consequently, we obtain 72 forecast error series (nine restricted models with eight variables). In total we have 81 forecast error series from the restricted and unrestricted models to conduct multivariate out-of-sample Granger causality tests. By comparing MSFEs between the unrestricted and restricted models, we find 46% (33 out of 72 cases) of the unrestricted models have lower MSFEs and, therefore, more accurate forecasts than the restricted model. This result invokes the principle of parsimony and over-fitting suggested by Box and Jenkins (1976). According to McCracken’s argument (1999), the unrestricted model having more extraneous variables generates accurate forecasts at least as well as the restricted model when we implement in-sample forecasting. In the case of out-of-sample forecasting, the unrestricted model containing more regressors is not guaranteed to have better predictive ability than the restricted model. The unrestricted model has lower predictive ability when the number of irrelevant regressors increases in the unrestricted model. However, since the difference of the MSFEs between the restricted and unrestricted models is quite small, a statistical DM test for the equal forecasting errors is conducted based upon equation (2.7).

Table 2.2 presents out-of-sample temporal granger causality test results. The null hypothesis is that each series in the first row does not Granger-cause any particular series in the first column given inclusion of other series in the first column. In the pre-break periods, captive supply Granger causes feeder cattle price, fed cattle futures price, and corn price. This implies that captive supply plays an important role in forecasting those prices. Meanwhile, captive supply is Granger caused by cattle inventory, fed cattle price, and retail beef price. Results indicate cattle inventory, fed cattle spot price, and retail beef price should be included to forecast one-month ahead captive supply. Cattle inventory is caused by HHI. Interestingly, fed cattle spot price and retail beef price are not caused by any other variables. In contrast, fed cattle futures price is caused by fed cattle spot price, retail beef price, corn price, and captive supply. Corn price causes boxed beef price, fed cattle spot price, and HHI.

Following the same procedure applied to the pre-break periods we conduct Granger causality tests for the post-break periods (1997:3-2005:8). With the same 60-month base widow, we obtain 42 one-step-ahead out-of-sample forecasts between 2002:3 and 2005:8.

As shown in Table 2.2, only six significant out-of-sample Granger causalities are found out of the 26 cases. That is, in six cases, the unrestricted model gives statistically better forecasting performance than the restricted model. In the post-break periods, captive supply Granger causes fed cattle price, which is opposite in the pre-break periods. Fed cattle price is also caused by feeder cattle price. Fed cattle price is warranted to forecast cattle inventory and fed cattle future price since they are caused by fed cattle price. Retail beef price is caused by boxed beef price.

We summarize the overall results on Granger temporal causality tests in Figure 2.7. The temporal causal relations among variables in the U.S. beef supply chain became much weaker after the structural change. Furthermore, in the post-break periods temporal causalities are mainly from upstream to downstream or in the same tier of the beef supply chain with the exception that fed cattle spot price Granger causes cattle inventory.

(b) Results of DAG Contemporaneous Causality

Table 2.1 shows the correlation matrices of contemporaneous innovations based on the estimated VECM in the pre- and post-break periods. Captive supply innovations are negatively correlated with most of other series in the U.S. beef supply chain, but are positively correlated with corn price in the pre-break periods, and feeder cattle price, retail beef price, and HHI in the post-break periods. Interestingly, captive supply innovations have a relatively stronger negative correlation with fed cattle spot price than that with other prices in both periods. Cattle inventory has negative correlations with other series except feeder cattle price in both periods and HHI in the post-break periods.

We also observe that innovations of spot cattle prices in the supply chain are highly correlated with each other except between feeder cattle price and retail beef price.

The contemporaneous causal structure of innovations based on the results of DAGs can be identified through the estimated correlation matrix from the VECM (Spirtes, Glymour, and Scheines, 2000; Pearl, 2000; Swanson and Granger, 1997). As shown in Figure 2.7, two DAGs, generated using TETRAD IV's GES algorithms, represent the direction of causal flows among variables in contemporaneous time in the pre- and post-break periods.[5]

Comparison of the two DAGs suggests that causalities change after the structural break in early 1997. The striking finding is that more contemporaneous causal relationships appear to be present in the post-break periods, which implies that information flow is quicker or more efficient within the beef supply chain in recent time than in times past. This is consistent with the temporal Granger causality results that show the opposite. Second, the direction of causalities appears to shift from downstream causal flows in the pre-break periods to upstream causal flows in the post-break periods. This means that before early 1997, most information in the supply chain appears to flow downstream, from cow-calf operations to packers. After early 1997, most information in the supply chain appears to flow upstream from retailers and packers to feeders and cow-calf operators. Further, before the structural break, it appears that price discovery in the supply chain occurred in box beef pricing where information from feeder steer prices,

[5] This contemporaneous causal structure can be used in a Bernanke factorization for orthogonalization to generate impulse responses and forecast error variance decompositions to describe the dynamic structure. However, since our main interest is to examine the causal relationship in the U.S. beef supply chain we do not further report those results. Innovation accounting results are available upon requests.

cattle inventory, and captive supply comes together to determine boxed beef price, the most endogenous variable. After the structural break, it appears that price discovery in the supply chain occurred in feeder steer pricing where information from fed cattle price, captive supply, and cattle inventory comes together to determine feeder steer price, the most endogenous variable. This reversal in information flow may result from increased concentration and use of contracts by packers and retailers in recent times.

Captive supply only indirectly causes fed cattle spot price in the pre-break periods, but it appears to directly cause feeder cattle price and fed cattle spot price in the post-break periods. In other words, captive supply appears to exhibit an increased contemporaneous influence on prices along the supply chain, which supports the argument that "the use of non-cash procurement leads to pressure on the spot market price" as several previous empirical studies have found. In recent periods, we observe that retail beef price causes fed cattle futures price but retail beef price is independent of other variables in the pre-break periods. This may be evidence of increasing power of retailers in cattle market pricing in the post-break period. Cattle inventory appears to directly cause corn price in both periods and cause feeder cattle price in post-break periods. These results are consistent with market intuition since cattle inventory is a primary factor determining cattle supply and therefore feed demand. The HHI for market concentration appears to have no influence on cattle prices in contemporaneous time. This result seems counter intuitive since a higher HHI implies packers are highly concentrated and may exercise more monopsony power lowering live cattle prices.

Perhaps this result suggests the difference between the ability to exercise market power and the actual exercise of market power (Jones et al., 1996).

Conclusions

This study investigates causalities among variables in the U.S. beef supply chain also identifies structural changes. The identified causal relations provide important information for future studies of the U.S. beef supply chain and might be used to inform future policy interventions.

Our empirical results suggest the following. First, based on the time-varying trace test results and the knowledge of historical events in the U.S. beef supply chain, we identify a significant structural change between late 1996 and early 1997 that corresponds to the 1996 grain shock and the turnaround of cattle inventory cycle. The 2001 Livestock Mandatory Price Reporting Act (LMPR) may contribute to another structural change based on recursive estimates, but the change was minor based on the rolling estimates. Similarly, the 2003 U.S. BSE discovery caused only a minor structural change. The 1996-1997 structural change is supported by the Box-M and Jennrich test as well as by comparison of dynamic recursive impulse responses and forecast error variance decomposition between two periods.

Second, we find that causal relationships in the U.S. beef supply chain changed after the structure change. Overall, the temporal causality becomes weaker but the contemporaneous causality becomes stronger after the structural break. The stronger contemporaneous causality after the structural break implies that new information or shocks emanating from a particular segment of the supply chain is more quickly and/or efficiently transmitted to the rest of the supply chain in the post-break periods compared with the pre-break periods. We speculate that faster and/or efficient information transmission along the supply chain results from increasing use of more efficient vertical coordination and contractual arrangements and possibly from implementation of mandatory livestock price reporting that improved fed cattle price reporting. In the post-break periods, the temporal causalities are mainly from upstream to downstream or in the same tier of the beef supply chain, while contemporaneous causalities indicate information flows downstream from retailers and packers to feeders and cow-calf operators. One might speculate that price discovery occurs in more competitive markets where market influences are more quickly incorporated into price. The switch in the point of price discovery from box beef price before 1997 to feeder cattle price after 1997 may be an indication that increased concentration and increased use of contracts by packers and retailers to gain greater economic control of supply chain.

Third, both the temporal and contemporaneous causality results show that captive supply directly causes fed cattle spot price in the post-break periods but only indirectly effects fed cattle price in the pre-break periods. The causal relationship between captive supply and fed cattle spot price strongly supports the argument that "the use of non-cash procurement leads to pressure on the spot market price" in several other empirical studies.

Clearly, increasing concentration and increased use of contracts to coordinated production and exchange between different tiers in the U.S. beef supply chain has affected the influence of different players in the system. Improved understanding of causal linkages among the different segments of the U.S. beef supply chain has rich policy implications for both policy makers and market participants. While it remains challenging to uncover causal relationships among variables using non-experimental observational data, the methods available today are allowing applied economists to gain some new understanding.

CHAPTER III

CONTRACT PRICING AND PACKER COMPETITION IN THE FED CATTLE MARKET

Recently, the U.S. cattle industry has undergone structural changes including increased concentration and a greater degree of quasi-vertical integration coordinated through contract procurement often referred to as captive supplies.[6] An implication of these trends is that packers are rapidly switching from traditional spot procurement in fed cattle markets to contract procurement. Possible motives for the switch to use contract procurement are to reduce price variability and manage risk and also to reduce transaction costs. Both packers and cattle producers can potentially benefit from contract sales as packers insure themselves against quantity short falls and price fluctuations and cattle producers secure reliable sales and smooth price volatility. For packers, a primary benefit from use of captive supply is to secure fed cattle requirements so packing plants can operate at the highest possible level of capacity utilization. In addition, they can potentially gain control over the type and quality of cattle and reduce procurement costs. However, contract procurement can reduce public market information because contract prices are frequently not reported due to nondisclosure rules. Furthermore, contract procurement may reduce competition in the fed cattle spot market, potentially leading to increased market power for packers (Ward and Schroeder, 1997). Contract procurement

[6] GIPSA defines “captive supply” as cattle owned or fed by a packer, procured through forward contracts and marketing agreements, and cattle that are otherwise committed to a packer more than 14 days prior to slaughter.

potentially allows packers to exercise price discrimination in procurement as different prices may be paid for cattle purchased through contracts and cattle procured through traditional spot markets. Hence, concerns about competitiveness among meatpackers arise.

While the evidence is not conclusive, most previous empirical studies generally suggest a negative relationship between captive supplies and spot market prices. Elam (1992) found individual states, Nebraska, Kansas, Colorado, and Texas, varied from no price difference to price reductions ranging from \$0.15/cwt to \$0.37/cwt. Hayenga and O'Brien (1992) compare the average weekly fed cattle price in the same four states and found no conclusive evidence that forward contracting decreased fed cattle prices. Schroeter and Azzam (2003) show a small statistically significant negative effect of captive supply volume on cash prices.

While most previous studies do not examine how contracts facilitate or extend market power, MacDonald, et al. (2004) argue that contracts can potentially amplify market power through entry deterrence, reduced price competition, and discriminatory pricing. They found packers have an incentive to use contract as a strategic variable for the purpose of increasing market power. Only a few theoretical studies have investigated how captive supplies may be used as a strategy to create or extend packer market power (Love and Burton, 1999; Zhang and Sexton, 2000; Wang and Jaenicke, 2006). Love and Burton (1999) formalize a strategic rationale whereby packers might use captive supplies to extend market power in cattle procurement. They show that a dominant beef processing firm has an incentive to backwardly integrate to simultaneously escape efficiency loss and exercise market power in spot market procurements. However, their model does not predict an unambiguous effect of backward integration on spot market price. Using a spatial model, Zhang and Sexton (2000) examine how strategic captive supply procurement can affect spot market price. Their model shows that the spot market cattle price can be reduced as transportation cost rises. Wang and Jaenicke (2006) show that how captive supplies affect the expected spot price under a formula price contract using a principal-agent approach.

Cattle feeders have increasing concerns about the effect of "Top-of-the-Market-Pricing (hereafter TOMP)" contracts on prices paid by packers for fed cattle.[7] Contract prices are often established based on either nearby spot market price or fed cattle futures market price. For example, under TOMP clauses, contract base price paid to producers is set as the highest spot price at delivery time. With TOMP clauses, packers have an incentive to compete less aggressively in spot markets in order to reduce input cost in contract markets. Recently, Xia and Sexton (2004) examined the effect of coexistence of spot and contract markets in a one-shot game framework where contract price is determined through TOMP clauses. They find that TOMP clauses reduce competition in the spot market and lower producers' profits. Ironically, they find that feeders favor the contract even though TOMP clauses lead to anti-competitive consequences for feeders. Even with lower equilibrium prices Xia and Sexton demonstrate that signing TOMP clauses is a dominant strategy for producers because a producer will suffer more loss

[7] TOMP clause is discussed first by Davis (2000)

without contracts. Their findings, however, are based on the assumption that contract price cannot deviate from spot market price.

In practice, contract prices reflect both observed and unobserved hedonic characteristics of fed cattle and stochastic market related influences. With heterogeneous quality characteristics, contract prices might deviate from spot prices giving packers a degree of latitude in setting contract price. In such a situation, packers have an incentive to transform bidding strategies in spot markets resulting in additional complications with respect to understanding the consequences of TOMP clauses on spot market price. For example, when there is a sufficiently large set of hedonic characteristics it may become hard to find the highest spot market price of the same kind of fed cattle. Widely heterogeneous hedonic characteristics will make it physically infeasible to trace the price on the spot markets for the same quality of cattle.

We extend Xia and Sexton's work on TOMP clauses by considering the effects of hedonic characteristics on contract price. This study addresses how contracts affect packer market power using a general pricing scheme which considers hedonic characteristics of cattle quality. We employ a stage game to investigate the effects of the contract procurement on packer competition in the spot market. In particular, we assume a more general relationship between contract price and spot market price, which allows us to capture the impacts of captive supply, hedonic characteristics of fed cattle, and unobserved stochastic components. Previous models are also extended by assuming cattle feeders may be risk averse.

The Model Structure

We assume a duopsony case in which there are two packers and N cattle feeders who are engaged in contract and spot markets. Each feeder only participates in one market, either the contract market or the spot market. We assume that feeders are risk averse and also price takers (i.e., non-strategic players). Packers are assumed to be risk neutral and to maximize expected profit from both markets. To facilitate the definition of notations, we use superscripts "*c*" and "*s*" to represent contract and spot markets, subscript i for packer i where $i=A$, B, and subscript k for feeder k where $k=1, 2, \ldots, N$.

Price Formulation in Both Markets

Spot market fed cattle prices are determined by negotiation or bidding. The bidding process for fed cattle procurement in spot market resembles a type of first-price sealed-bid auction, in which, the highest bidder wins the cattle in a feedlot. Formula pricing with various types of base price are the most general pricing method for fed cattle transactions in the contract market. The formula base price is usually derived from the various external prices including the average price paid at a slaughter plant, wholesale prices, futures prices, or reported market average prices (Ward, Schroeder and Feuz, 1997). Fed cattle may be valued on live weight basis, carcass (dressed) weight basis, or grid pricing. Live weight or carcass pricing methods apply a uniform average price for the entire lot, while grid pricing is established on a carcass basis. Most spot market sales are priced on a live weight basis while contact sales are based on carcass weight since most formulas are based upon dressed weights.

We assume feeders who accept the contract are paid a higher base price than in the spot market. However, on average, the observed contract price can deviate from the base price to reflect cattle quality attributes or so-called hedonic characteristics. Pricing methods in both spot and contract markets are linked to cattle quality attributes, $\mathbf{z}_k^m$, associated with feeder *k* and cattle market *m* (spot = *s* or contract = *c*). Various factors differentiate cattle quality attributes, including average live weight of cattle, average dressing percentage of cattle, number of head in the lot, distance from the feedlot to slaughter plant, type of cattle, yield grade and quality grade of feedlots. We emphasize one particular factor which plays a vital role in determining cattle quality, the effort of each feeder. Feeders' efforts, denoted by e_k^m, influence management-based activities which are important to quality attributes. Therefore, quality difference which causes price differentiation in each feedlot is reflected in different feeder effort levels.

Assumption 1. *The hedonic characteristic function is*

(3.1) $\mathbf{z}(e_k^m) = \delta e_k^m + \varepsilon_m$

where ε_m is unobserved stochastic component in each market m with $E(\varepsilon^m) = 0$, $Var(\varepsilon^m) = \sigma_{\mathbf{z}}^2$ and δ is quality price premium. Realized hedonic characteristics, $\mathbf{z}(e_k^m)$ is assumed to follow a normally distribution which depends on feeders' efforts: $\mathbf{z}(e_k^m) \sim N(\delta e_k^m, \sigma_{\mathbf{z}}^2)$. The marginal effect of feeders' effort on cattle expected quality attributes and variance are $\frac{\partial \bar{\mathbf{z}}(e_k^m)}{\partial e_k^m} = \delta$ and $\frac{\partial Var(\mathbf{z}(e_k^m))}{\partial e_k^m} = 0$. We assume the effects are the same in both the contract and cash markets. Assumption 1 suggests a constant and positive marginal effect of feeders' effort on cattle quality attributes, $\delta > 0$. Feeders utilizing a higher effort level will delivery a better quality attributes of their cattle. However, the expected cattle attributes, $\bar{\mathbf{z}}(e_k^m)$, which depend on feeder's effort level, may not be the same in both the contract and spot market even though the marginal effect is constant with respect to different markets. If equilibrium price is higher in one market, feeders may exercise more effort because the marginal gain is higher. Packers pay for quality attributes rather than feeders' effort level. Thus, a potential moral hazard problem is avoided since quality attributes can be observed in both spot and contract markets, while feeders' effort is privately held information.[8]

Assumption 2. *Spot market transaction price paid to feeder k is*

(3.2) $$W_k^s = w^s + \mathbf{z}(e_k^s) = w^s + \delta e_k^s + \varepsilon_s$$

where w^s is a market clearing price component not relating to hedonic quality attributes in spot market. Assumption 2 suggests that actual transaction price in the spot market can be decomposed into a market price component and a non-market hedonic price component. The market price component, w^s, can be considered as the spot market equilibrium price resulting from equilibrium between demand and supply in spot market.

Assumption 3. *Contract market transaction price paid to feeder k is* [9]

(3.3) $$W_k^c = (1+\beta)w^s + \mathbf{z}(e_k^c) = (1+\beta)w^s + \delta e_k^c + \varepsilon_c$$

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[8] Packer does not care about feeder's effort level even though it has an effect on $\mathbf{z}_k^m$ since a packer is only paying for the quality actually observed or obtained when she prices the cattle in both market. Thus, the pricing method which depend in part on feeder's effort level naturally induces feeder's best effort in both markets.

[9] Xia and Sexton's model assume the deviation of contract price from spot market price is not allowed. In their model, contract price for each feeder is always same with the spot price: $W_i^c = W_j^c = h(W^s) = w^s$

Assumption 3 is consistent with the linear procurement contract commonly used in cattle industry. Packers normally procure cattle by lot instead of buying individual cattle. Thus, reported prices are based on the average cattle characteristics of the lots sold in specified periods and geographic areas. We assume the average spot market price as the base price of contract market. Hedonic characteristics of cattle sold in the contract market are included in contract market pricing to reflect quality differences between each feedlot in the contract market. In the linear contract, packer's choice variable is β, or the price premium or discount paid for contact cattle in relation to cattle purchased in the spot market. We expect β is greater than 0, which ensures that feeders who accept contract will have a higher price than those in the spot market. We will examine our expectation later to confirm.

Assumption 4. *Output market price (boxed beef price) paid to packer is given by:*

(3.4) $$p^m = \tilde{p} + \mathbf{z}(e_k^m) = \tilde{p} + \left(\delta e_k^m + \varepsilon_m\right)$$

Assumption 4 suggests that reported output (beef) prices also depend on the average cattle quality provided by the packers.

Stage Game

Figure 3.1 illustrates the stage game by specifying the actions undertaken by packers and feeders and the corresponding choice variables in each stage. We assume this game evolves in two stages, and both contract and spot markets sequentially evolve.

- **Stage I**: Each packer, A and B, chooses contract terms, β, which results in a number of contract feeders, n_A^c and n_B^c, who signed a contract. Given contract terms, β, feeders decide whether to signed a contract with a packer i and choose the optimal output and effort level to maximize their expected utility.

- **Stage II**: ($N - n_A^c - n_B^c$) feeders who sell their products in the spot market choose the optimal output and effort level to maximize their expected utility. Packers choose the quantities of cattle to purchase in the spot market to maximize expected profit.

In first stage, packers decide weights that they apply to the average spot market price as the base price and the price premium paid to certain quantity attributes. Feeders who are offered the contract decide to accept or reject the offer. Feeders will accept the contract if they obtain a high profit by participating in the contract market. We assume that feeders who are offered the contract always accept the contract to sell on the contract market when solving the stage game.[10] We revisit this issue by compare the profit without contract and with contract later to confirm our assumption.

In second stage, all feeders no matter whether they accept the contract or not, choose an effort level to optimally produce quality attributes. Packers A and B compete in the spot market to purchase cattle that are not committed in the contract market to maximize expected profit. That is, packers A and B purchase cattle from n_A^s and n_B^s feeders in the spot market. Given the game structure illustrated in Figure 3.1, we use backward induction to analytically solve for the Bayes perfect equilibrium.

[10] In real market contract price is, on average, higher than spot price. Xia and Sexton (2004) show why rational producers accept the contract

Stage II: Spot Market

Suppose that $(n_A^c + n_B^c)$ feeders already signed the contract with a processing firm. There are $N-(n_A^c + n_B^c)$ feeders left in the spot market to sell their fed cattle. Aggregate spot market supply is assumed to result from feeder's cost given by:

(3.5.a) $c(e_k^s) = \frac{1}{2}\left(e_k^s\right)^2$, and

(3.5.b) $c(x_k^s) = \frac{1}{2}\left(x_k^s\right)^2$,

where cost, $c(\cdot)$ is a positive increasing function of effort, e_k^s. Each feeder's profit function in spot market is given by:

$$(3.6) \qquad \pi_k^{F,s} = W_k^s x_k^s - \left(\frac{1}{2}\left(x_k^s\right)^2 + \frac{1}{2}\left(e_k^s\right)^2\right) = \left(w^s + \delta e_k^s + \varepsilon^s\right)x_k^s - \left(\frac{1}{2}\left(x_k^s\right)^2 + \frac{1}{2}\left(e_k^s\right)^2\right).$$

where x_k^s is quantity produced by an individual feeder in spot market. Also, we assume that each feeder can be characterized as maintaining constant absolute risk adverse preferences given by an exponential utility. Since, revenue is normally distributed, feeder *k*'s expected utility function can be expressed as an increasing concave function of the mean-variance utility which corresponds to the certainty equivalent value of revenue.

$$(3.7) \qquad EU(\pi_k^{F,s}) = E(\pi_k^{F,s}) - \frac{\gamma}{2}Var(\pi_k^{F,s}).$$

where $\gamma > 0$ is a constant absolute risk aversion parameter. The variance of feeder *k*'s profit is given by

(3.8) $Var(\pi_k^{F,s}) = \delta^2 E\left(\mathbf{z}(e_k^s) - \overline{\mathbf{z}}(e_k^s)\right)^2 = \delta^2 \sigma_{\mathbf{z}}^{2,s}$.

Then, we can rewrite feeder k's expected utility function using (3.6) and (3.8)

(3.9) $EU(\pi_k^{F,s}) = \left(w^s + \delta e_k^s\right)x_k^s - \left(\frac{1}{2}\left(x_k^s\right)^2 + \frac{1}{2}\left(e_k^s\right)^2\right) - \frac{\gamma\sigma_{\mathbf{z}}^2}{2}(x_k^s)^2$.

From equation (3.9), we obtain individual feeder's spot supply function as follows:

(3.10.a) $x_k^s = \dfrac{w^s + \delta e_k^s}{1 + \gamma\sigma_{\mathbf{z}}^2}$.

Cost of effort for an individual feeder in the spot market is as follows:

(3.10.b) $e_k^s = \delta x_k^s$.

Substituting equation (3.10.b) into equation (3.10.a) gives an individual feeder's spot supply function can be rewritten as:

(3.11) $x_k^s = \dfrac{w^s}{1 + \left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}$.

The cost of effort in spot market is:

(3.12) $e_k^s = \dfrac{\delta w^s}{1 + \left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}$.

From equation (3.11), aggregate feeder spot market supply is:

(3.13) $X_S^s = (N - n_A^c - n_B^c)x_k^s = \dfrac{(N - n_A^c - n_B^c)w^s}{1 + \left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}$.

Equilibrium spot market demand with two packers requires:

(3.14) $X_D^s = X_A^s + X_B^s$.

The market is cleared when $X_S^s = X_D^s$ and the market equilibrium spot price, w^s, is established when aggregate supply equals aggregated demand. From equation (3.12) and (3.13), we obtain spot market equilibrium price:

(3.15) $$w^s = \frac{\left(X_A^s + X_B^s\right)\left(1+\left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)\right)}{(N - n_A^c - n_B^c)}.$$

Total profit for packer *i* from both the contract and spot market procurement is:

(3.16) $$\pi_i = [p^c - W_i^c]X_i^c + [p^s - W_i^s]X_i^s - TC(X_i^c, X_i^s; \mathbf{v}) \quad \text{for } i = \text{A, B}$$

where $TC(\cdot)$ is total processing cost for packer *i*, which is assumed to be constant returns to scale, n_i^m is a number of feeders in the contract (*m*=*c*) or spot (*m*=*s*) markets. In stage II, packers choose the quantity of cattle to purchase in the spot market, X_i^s, given that he/she already has a contract quantity, X_i^c. That is, packer *i* maximizes expected profit specified in equation (3.16) by choosing X_i^s. Taking the derivate of equation (3.16) with respect to X_i^s yields packer *i's* best response function:

(3.17)

$$\frac{\partial E\pi_i}{\partial X_i^s} = -\left(\frac{(1+\beta)\left(1+\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}{N - n_A^c - n_B^c}\right)X_i^c + \tilde{p} - \frac{\left(X_A^s + X_B^s\right)\left(1+\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}{N - n_A^c - n_B^c} - \left(\frac{1+\gamma\sigma_{\mathbf{z}}^2 - \delta^2}{N - n_A^c - n_B^c}\right)X_i^s = 0.$$

Based on equation (3.17) we are able to derive the best response function of each packer:

(3.18.a) $$X_A^s = \frac{(N - n_A^c - n_B^c)\tilde{p}}{2\left(\left(1+\gamma\sigma_{\mathbf{z}}^2\right) - \delta^2\right)} - \frac{X_B^s}{2} - \frac{(1+\beta)}{2}X_A^c$$

(3.18.b) $$X_B^s = \frac{(N - n_A^c - n_B^c)\tilde{p}}{2\left(\left(1+\gamma\sigma_{\mathbf{z}}^2\right) - \delta^2\right)} - \frac{X_A^s}{2} - \frac{(1+\beta)}{2}X_B^c.$$

Solving equations (3.18.a) and (3.18.b) simultaneously yields the Cournot-Nash equilibrium quantities, (X_A^s, X_B^s), in the spot market conditional on the contract market equilibrium:

(3.19.a) $$X_A^s = \frac{(N - n_A^c - n_B^c)\tilde{p}}{3\left(\left(1+\gamma\sigma_{\mathbf{z}}^2\right) - \delta^2\right)} - \frac{(1+\beta)\left(2X_A^c - X_B^c\right)}{3},$$

(3.19.b) $$X_B^s = \frac{(N - n_A^c - n_B^c)\tilde{p}}{3\left(\left(1+\gamma\sigma_{\mathbf{z}}^2\right) - \delta^2\right)} - \frac{(1+\beta)\left(2X_B^c - X_A^c\right)}{3}.$$

Substituting equations (3.19.a) and (3.19.b) into equation (3.15) yields the spot market equilibrium price not relating with quality attributes:

$$w^s = \frac{2\tilde{p}}{3} - \frac{(1+\beta)\left(1+\left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)\right)\left(n_A^c + n_B^c\right)}{3(N - n_A^c - n_B^c)} x_k^c.$$

Using the result from substitution of spot market equilibrium price into the individual feeder's spot supply function of equation (3.10.a) and spot market effort cost function of equation (3.12), we obtain actual spot market price paid to feeder *k* from equation.

$$W_k^s = \frac{2\left(1+\gamma\sigma_{\mathbf{z}}^2\right)\tilde{p}}{3\left(1+\left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)\right)} - \frac{(1+\beta)\left(n_A^c + n_B^c\right)\left(1+\gamma\sigma_{\mathbf{z}}^2\right)}{3(N - n_A^c - n_B^c)} x_k^c + \varepsilon^s.$$

Output spot price paid to packer *i* from equation (3.4) can be rewritten as:

$$p^s = \tilde{p}\left(1 + \frac{2\delta^2}{3\left(1+\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}\right) - \frac{\delta^2(1+\beta)\left(n_A^c + n_B^c\right)}{3(N - n_A^c - n_B^c)} x_k^c + \varepsilon^s.$$

Stage I: Contract Market

In the contract market, the model structure for each feeder is the same as in the spot market. Thus, the feeder *k*'s expected utility function in contract market is:

$$(3.20)\quad EU(\pi_k^{F,c}) = \left((1+\beta)w^s + \delta e_k^c\right)x_k^c - \left(\frac{1}{2}\left(x_k^c\right)^2 + \frac{1}{2}\left(e_k^c\right)^2\right) - \frac{\gamma\sigma_{\mathbf{z}}^2}{2}(x_k^c)$$

From equation (3.20), we obtain individual feeder's supply and cost of effort in the contract market as:

$$(3.21)\quad x_k^c = \frac{(1+\beta)w^s + \delta e_k^c}{1+\gamma\sigma_{\mathbf{z}}^2}$$

and,

$$(3.22)\quad e_k^c = \delta x_k^c \ .$$

Substituting equation (3.22) into equation (3.21), an individual feeder's contract supply can be rewritten as $x_k^c = \frac{\widetilde{p}(1+\beta)}{1+\left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}\left(\frac{2(N-n_A^c-n_B^c)}{3(N-n_A^c-n_B^c)+(1+\beta)^2(n_A^c+n_B^c)}\right)$. Cost of effort in the contract market is $e_k^c = \frac{\delta\widetilde{p}(1+\beta)}{1+\left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}\left(\frac{2(N-n_A^c-n_B^c)}{3(N-n_A^c-n_B^c)+(1+\beta)^2(n_A^c+n_B^c)}\right)$.

Further, since aggregate contract market feeder supply is, $X_S^c = (n_A^c + n_B^c)x_k^c$, contract price, W_k^c, and output price, p^c, are respectively:

$$X_S^c = (n_A^c + n_B^c)x_k^c = \frac{\widetilde{p}(1+\beta)}{1+\left(\gamma\sigma_{\mathbf{z}}^2 - \delta^2\right)}\left(\frac{2(N-n_A^c-n_B^c)(n_A^c+n_B^c)}{3(N-n_A^c-n_B^c)+(1+\beta)^2(n_A^c+n_B^c)}\right),$$

$$W_k^c = \frac{2\widetilde{p}(1+\beta)\left(1+\gamma\sigma_{\mathbf{z}}^2\right)}{3\left(\left(1+\gamma\sigma_{\mathbf{z}}^2\right)-\delta^2\right)} - (1+\beta)^2\left(\frac{(n_A^c+n_B^c)\left(1+\gamma\sigma_{\mathbf{z}}^2\right)}{3(1-n_A^c-n_B^c)}\right)x_k^c + \varepsilon_c,$$

$$p^c = \widetilde{p} + \delta^2\left(\frac{2\widetilde{p}(1+\beta)}{3\left(1+\left(\gamma\sigma_{\mathbf{z}}^2-\delta^2\right)\right)} - \frac{(1+\beta)^2\left(n_A^c+n_B^c\right)}{3(1-n_A^c-n_B^c)}x_k^c\right) + \varepsilon_c .$$

Total expected profit for packer *i* is:

(3.23) $E\pi_i = E\{[p^c - W_i^c]n_A^c x_k^c + [p^s - W_i^s]X_i^s - TC(X_i^c, X_i^s; \mathbf{v})\}$ for $i = A, B.$

Feeders maximize expected profit in the first stage by choosing optimal quantity and number of contract feeders. We assume homogenous feeders, individual and aggregate supply, cost of effort, market clearing spot price, and output price in both the contract and spot market can be rewritten as:

$$x^c = \frac{2(1+\beta)\tilde{p}}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^2 S}\right);$$

$$x_k^s = x^s = \frac{x^c}{1+\beta} = \frac{2\tilde{p}}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^2 S}\right);$$

$$e_k^c = e^c = \delta x^c = \frac{2(1+\beta)\tilde{p}\delta}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^2 S}\right);$$

$$e_k^s = e^s = \delta x^s = \frac{2\tilde{p}\delta}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^2 S}\right);$$

$$X_A^s = X_B^s = X^s = \frac{\tilde{p}}{R}\left(\frac{(N-S)^2}{3(N-S)+(1+\beta)^2 S}\right);$$

$$X_A^c = X_B^c = X^c = \frac{(1+\beta)\tilde{p}}{R}\left(\frac{(N-S)^2}{3(N-S)+(1+\beta)^2 S}\right);$$

$$w^s = \frac{2\tilde{p}(N-S)}{3(N-S)+(1+\beta)^2 S};$$

$$E(W_k^s) = \frac{2\tilde{p}(R+\delta^2)}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^2 S}\right);$$

$$E(W_k^c) = \left(\frac{2(1+\beta)\tilde{p}(R+\delta^2)}{R}\right)\left(\frac{(N-S)}{3(N-S)+(1+\beta)^2 S}\right);$$

$$E\left(p^{s}\right)=\widetilde{p}\left(1+\frac{2\delta^{2}}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^{2}S}\right)\right);$$

$$E\left(p^{c}\right)=\widetilde{p}\left(1+\frac{2(1+\beta)\delta^{2}}{R}\left(\frac{(N-S)}{3(N-S)+(1+\beta)^{2}S}\right)\right);$$

where $\left(1+\left(\gamma\sigma_{\mathbf{z}}^{2}-\delta^{2}\right)\right)=R$, $n_{A}^{c}+n_{B}^{c}=S$.

With these results, expected packer profit given in equation (3.23) can be rewritten as:

$$(3.24)\ E\pi_{i}=\frac{\widetilde{p}^{2}}{R}\left(\left(\frac{(N-S)(1+\beta S)}{3(N-S)+(1+\beta)^{2}S}\right)-2\left(\frac{(N-S)}{3(N-S)+(1+\beta)^{2}S}\right)^{2}\left((1+\beta)^{2}S-(N-S)\right)\right)$$

To maximize packer i's expected profit, the derivative of packer i's total profit given by equation (3.24) is obtained with respect to β and S, and the resulting first order conditions define the packer's optimal choices for β and S.

$$(3.25.a)\ \frac{\partial E\pi_{i}}{\partial S}=F_{1}=\frac{2\widetilde{p}^{2}(1+\beta)}{R}\left[\frac{N\beta-1-2\beta S}{3(N-S)+(1+\beta)^{2}S}\right.$$

$$-\frac{(N-S)(1+\beta S)\left((1+\beta)^{2}-3\right)}{\left(3(N-S)+(1+\beta)^{2}S\right)^{2}}+\frac{4(N-S)\left((1+\beta)^{2}S-N+S\right)}{\left(3(N-S)+(1+\beta)^{2}S\right)^{2}}-\frac{2(N-S)^{2}\left((1+\beta)^{2}+1\right)}{\left(3(N-S)+(1+\beta)^{2}S\right)^{2}}$$

$$\left.+\frac{4(N-S)^{2}\left((1+\beta)^{2}S-1+S\right)\left((1+\beta)^{2}-3\right)}{\left(3(N-S)+(1+\beta)^{2}S\right)^{3}}\right]=0$$

(3.25.b)

$$\frac{\partial E\pi_{i}}{\partial\beta}=F_{2}=\frac{2\widetilde{p}^{2}(1+\beta)}{R}\left[\frac{(N-S)S}{3(N-S)+(1+\beta)^{2}S}-\frac{2(N-S)(1+\beta S)(1+\beta)S}{\left(3(N-S)+(1+\beta)^{2}S\right)^{2}}-\frac{4(N-S)^{2}(1+\beta)S}{\left(3(N-S)+(1+\beta)^{2}S\right)^{2}}\right.$$

$$\left.+\frac{8(N-S)^{2}\left((1+\beta)^{2}S+S-N\right)(1+\beta)S}{\left(3(N-S)+(1+\beta)^{2}S\right)^{2}}\right]=0$$

Unfortunately, no closed form solution can be obtained for these equations. However, a numeric solution for the equilibrium can be obtained using equations (3.25.a) and (3.25.b). Figure 3.2 shows conditions under which the first order conditions are satisfied for β and S. The Bayes perfect Nash-equilibrium requires the two first order conditions to be simultaneously satisfied. Figure 3.3 presents numerical results for Bayes perfect Nash equilibrium that shows $\beta^* = 1.09$ and $S^* = 0.405 \cdot N$.

The result of $\beta^* = 1.09$ satisfies our expectation that feeders who accept a packer contract receive a higher price than in the spot market. Therefore, packer contract purchases impose an externality on spot market competition. That is, contract transactions are used by packers to exercise 2nd degree price discrimination by exercising differential pricing in the spot and contract market. This result is consistent with Xia and Sexton's (2004) TOMP study. The equilibrium solution also shows the optimal number of contract feeders represents 40.5% of all feeders in the industry. Figure 2 shows β^* and S^* in case of total one hundred of feeders (N = 100) in both spot and contract market.

Comparative Static Results

We conduct comparative static analysis to better understand how changes in output price ($\tilde{p}$), feeder risk aversion (γ), the price premium of paid for quality attributes (δ), and the variation in the effects of feeder effort on hedonic quality attributes (σ^2) affect feeder supply, cattle prices, and optimal feeder effort in both spot and contract markets. To obtain the comparative statistic results, the first order equations (3.25.a) and (3.25.b) for optimal S and β are totally differentiated with respect to the four parameters ($\tilde{p},\gamma,\delta,\sigma^2$) and then simultaneously solved using Cramer's rule.

Tables 3.1 and 3.2 summarize the comparative statistic results. The results show that output price ($\tilde{p}$), and price premium paid for quality attributes (δ) have positive effects on feeder supply, cattle prices, and optimal feeder effort level in both the spot and contract markets. In contrast, feeder risk aversion (γ), and the variation in the effects of feeder effort on hedonic quality attributes (σ^2) negatively affect feeder supply, cattle prices, and optimal feeder effort in both spot and contract markets.

Conclusions

Packers are rapidly switching from traditional spot procurement in fed cattle markets to contract procurement. Possible motives for the switch to use contract procurement are to reduce price variability and manage risk and possibly increase product quality. However, contract procurement may reduce competition in the fed cattle spot market, potentially leading to increased market power for packers (Ward and Schroeder, 1997). Contract procurement potentially allows packers to exercise price discrimination in procurement as different prices may be paid for cattle purchased through contracts and cattle procured through traditional spot markets. Hence, concerns about competitiveness among meatpackers arise.

A game-theoretic framework is used to analyze the coexistence of spot and contract markets in the cattle industry in a framework that allows both endogenously determined quality and risk adverse feeders. We consider two packers competing for purchases from

N feeders to reflect the cattle industry. Results show that packers find it optimal to use contract markets to price discriminate between purchases made in the contract and spot markets. This may be one reason why packers only purchase a portion of cattle in the contract market. Packers have an incentive to maintain contract and spot market purchases as a means to exercising price discrimination between markets and risk adverse feeders and quality attributes alone cannot explain the price differentials generated in equilibrium.

Comparative static results show that output price and price premium paid for quality attributes have positive effects on feeder supply, cattle prices, and optimal feeder effort in both the spot and contract markets. In contrast, feeder risk aversion and the variation in the effects of feeder effort on hedonic quality attributes negatively affect feeder supply, cattle prices, and optimal feeder effort in both spot and contract markets.

The results may shed light on understanding potential effects of captive supplies on market power and may aid in the assessment of the policies designed to enhance competition in the cattle industry. However, there are a number of limitations. In this study, we imposed symmetric conditions between production in the spot and contract markets. These conditions may be too strict. Further, it is not possible to obtain a closed form solution in for current model. Future work should include a welfare analysis of the effects on market participants of changes in important model parameters.

CHAPTER IV

THE IMPACT 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 UPClevel 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:

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

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 (4.1) becomes

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

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

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 and 1991) with test statistic given by

$$(4.3) \quad \text{Trace} = -T\sum_{i=r+1}^{k}\ln(1-\lambda_i)$$

where T is the number of observations and λ_i's are ordered eigenvalues of matrix Π in equations (4.2.a) and (4.2.b). 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; 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,

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

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, 2008) 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 (4.1) into moving average presentation,

(4.5) $$X_t = \sum_{i=0}^{\infty} \Theta_i \varepsilon_{t-i} ,$$

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.

(a) Converting to 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

(4.6) $$\varepsilon_t = Ae_t .$$

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:

$$\text{(4.7)} \quad \Pr(x_1, x_2, x_3, \ldots\ldots., x_n) = \prod_{i=1}^{n} \Pr(x_i \mid pa_i),$$

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:

$$\text{(4.8)} \quad \mathrm{S}(\mathrm{G}, \mathrm{D}) = \ln p(D \mid \hat{\theta}, G^k) - \frac{d}{2} \ln T,$$

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)

(b) 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:

(4.9) $$X_{T+k} = \sum_{s=k}^{\infty} \Theta_s \varepsilon_{T+k-s} + \sum_{s=0}^{k-1} \Theta_s \varepsilon_{T+k-s}.$$

The first term in the right-hand side of equation (4.9), 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}.

The Korean Meat Market and Animal Disease Outbreaks [11]

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

[11] 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.

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.

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.,[12] 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.

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 4.1 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.

[12] 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.

Empirical Findings and Discussion

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 4.1 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 above section, 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 4.2, 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 4.3 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 4.2). 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 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.[13]

We use the same procedure to conduct forecasting of meat pries 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. In terms of what information to use for the estimation and forecasting relating to the AI/BSE events, we have two options: (a) using a large sample consisting of the information from January 1985 to November 2003 despite of the structural change induced by the FMD outbreak in April 2000; and (b) using a small

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[13] 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.

sample including the information after the FMD outbreak, i.e. from May 2000 to November 2003, to avoid the impacts of the structure change. We then 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. The *t*-statistics of 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 with degree of freedom of 36 at the 5% significance level (1.690). Hence, we reject the null hypotheses at the 5% significance level in all cases except wholesale pork price (WP). 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, (4.10) $\Delta P_{ij}^{d} = \frac{x_{ij}^{d} - F_{ij}^{d}}{F_{ij}^{d}} \times 100$.

(a) The Impacts of the Domestic FMD Outbreak on Meat Prices

Figure 4.3 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 4.3a and 4.3b 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 4.3b 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.

(b) The Impacts of the AI/BSE Incidents in December 2003 on Meat Prices

Figure 4.4 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 4.4a, 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 4.4a 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 4.4c 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 4.4b clearly shows that the pork market gained from the incidents as the prices increased, which may be contributed to consumption substitution.

(c) Differentiating 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 4.3 and 4.4, 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 2000 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 $PM_{i,rf}^{d}$ that is affected by animal disease outbreak *d* is $x_{ir}^{d} - x_{if}^{d}$, and it is $F_{ir}^{d} - F_{if}^{d}$ 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 (4.11.a). Similarly, the change of the wholesale-to-farm and the retail-to-wholesale price margin are in equations (4.11.b) and (4.11.c), respectively.

(4.11.a) $$PM_{i,rf}^{d} = \left(x_{ir}^{d} - x_{if}^{d}\right) - \left(F_{ir}^{d} - F_{if}^{d}\right),$$ retail-to-farm

(4.11.b) $$PM_{i,wf}^{d} = \left(x_{iw}^{d} - x_{if}^{d}\right) - \left(F_{iw}^{d} - F_{if}^{d}\right),$$ wholesale-to-farm

(4.11.c) $$PM_{i,rw}^{d} = \left(x_{ir}^{d} - x_{iw}^{d}\right) - \left(F_{ir}^{d} - F_{iw}^{d}\right).$$ retail-to-wholesale

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

(a) The Impacts of the 2000 FMD Outbreak on Price Margins

Figure 4.5 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 [14]). 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.

(b) The Impacts of the 2003 AI/BSE Incidents on 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 farm 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).

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[14] 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 4.7 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 4.7, we employ TETRAD IV with the GES algorithm to identify the causal flows between contemporaneous price innovations.[15] The results in Figure 4.8 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.

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[15] 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 4.9 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 4.9a 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 4.9b 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 4.9 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.

Conclusions

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 April 2000 induced a significant structural change in the Korean meat price system. However, the domestic AI incidents and the U.S. BSE discovery in December 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 along the supply chain, 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.

CHAPTER V

SUMMARY AND CONCLUSIONS

This dissertation uses empirical time series methods and a game theory based model to investigate the meat supply chain of two counties. Causal and dynamic relationships among variables in the U.S. cattle supply chain are investigated. Motives for packer use of contract procurement are identified. And impacts of animal disease outbreaks on the Korean meat supply chain are investigated.

The first objective of this study is to investigate causal relationships among variables in the U.S. cattle supply chain to enhance understanding of the U.S. cattle sector. Based on time-varying trace test results and the knowledge of historical events in the U.S. cattle supply chain, we identify two significant regime changes corresponding to the 1996 grain shock and the 2001 Livestock Mandatory Price Reporting Act (LMPR) during the study time horizon (1988-2005). Granger temporal causality test results suggest the overall temporal causality in the U.S. cattle supply chain becomes weak after the structural change though relatively strong causalities are found in pre-break periods. More extensive contemporaneous causal relationships are found in post-break periods. Both causality test results shows that captive supply directly causes fed cattle spot prices in post-break periods but has only indirect impacts in pre-break periods. The causal relationship between captive supply and fed cattle spot prices strongly supports the argument that "the use of non-cash procurement leads to pressure on the spot market price" in several previous empirical works.

The second objective is to develop a dynamic game theoretic framework to investigate the incentives for, and the dynamic effects of, contract and spot market cattle procurement by packers. To examine the effect on spot price under the coexistence of spot and contract markets in the cattle industry a game-theoretic model is developed. A duopsony scenario with two packers and *N* feeders is used to reflect the reality in the cattle industry. An important contribution is to incorporate the feeder risk and hedonic pricing of cattle quality attributes that result form feeder effort in the model. Results show that packers have an incentive to maintain contract and spot market purchase as a means to exercising price discrimination between markets and that risk adverse feeders and quality attributes alone cannot explain the price differentials generated in equilibrium. The results may shed light on understanding potential effects of captive supplies on market power and may aid in the assessment of the policies designed to enhance competition in the cattle industry.

The final objective is to investigate the impacts of animal disease outbreaks on the Korean meat market, price margins along the supply chain, and price interdependence in the meat supply chain. Results indicate that animal disease outbreaks caused a temporary price shock to the Korean meat market regardless of whether it originated overseas or in the domestic market and regardless of disease type (FMD, AI, or BSE). In addition, retailers likely to have windfall profits as the retail price margin in creased relative to the farm and wholesale levels. This is because retail market in general is highly concentrated in Korea. Given the concentrated retail market in Korea, our results imply that exogenous shocks like animal disease outbreaks can influence the price margin along the supply chain when market power exists. While, we discover that the wholesale-to-farm price margin was relatively stable. The results from historical decomposition of price innovations 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.

This dissertation has some limitations. In chapter II, we analyze causal relationship of two sub-periods based on structural break tests although both trace tests suggest at least two significant break points. Due to the degrees of freedom problem, however, only a single significant break point is chosen. With more observations, it would be interesting to explore more reliable causal relationships. In addition, Sup-LM or Sup-LR test developed by Andrews (1993) can be considered as an alternative methodology to examine structural breaks.

In chapter III, we imposed the symmetric conditions in both spot and contract market. The symmetric condition, however, is too strict to investigate more precise and real market characteristics. An analysis of welfare effects on market participants is not conducted in this chapter.

In chapter IV, we only considered domestic prices in the meat supply chain because of lack of data on imported meat price. Hence, the currently available data does not allow us to explain the role of imported meat prices on 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 a 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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APPENDIX A

NOMENCLATURE

BOXP	Boxed Beef Price
CAPT	Captive Supply
CORP	Corn Price
FB	Farm Beef
FC	Farm Chicken
FP	Farm Pork
FEDP	Feeder Cattle Price
FEEP	Fed Cattle Spot Price
FUTP	Fed Cattle Futures Price
HHI	Hirfindahl-Hirschman Index
INVT	Cattle Inventory
RB	Retail Beef
RC	Retail Chicken
RP	Retail Pork
REBP	Retail Beef Price
WB	Wholesale Beef
WC	Wholesale Chicken
WP	Wholesale Pork

APPENDIX B

FIGURES

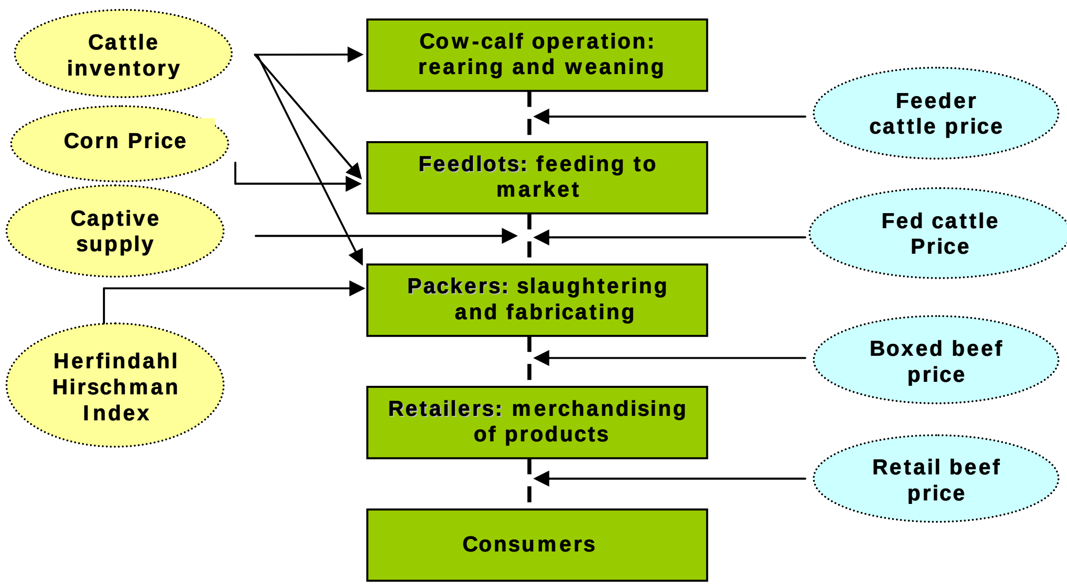


Figure 2.1. Overview of beef production segments in the U.S. cattle supply chain

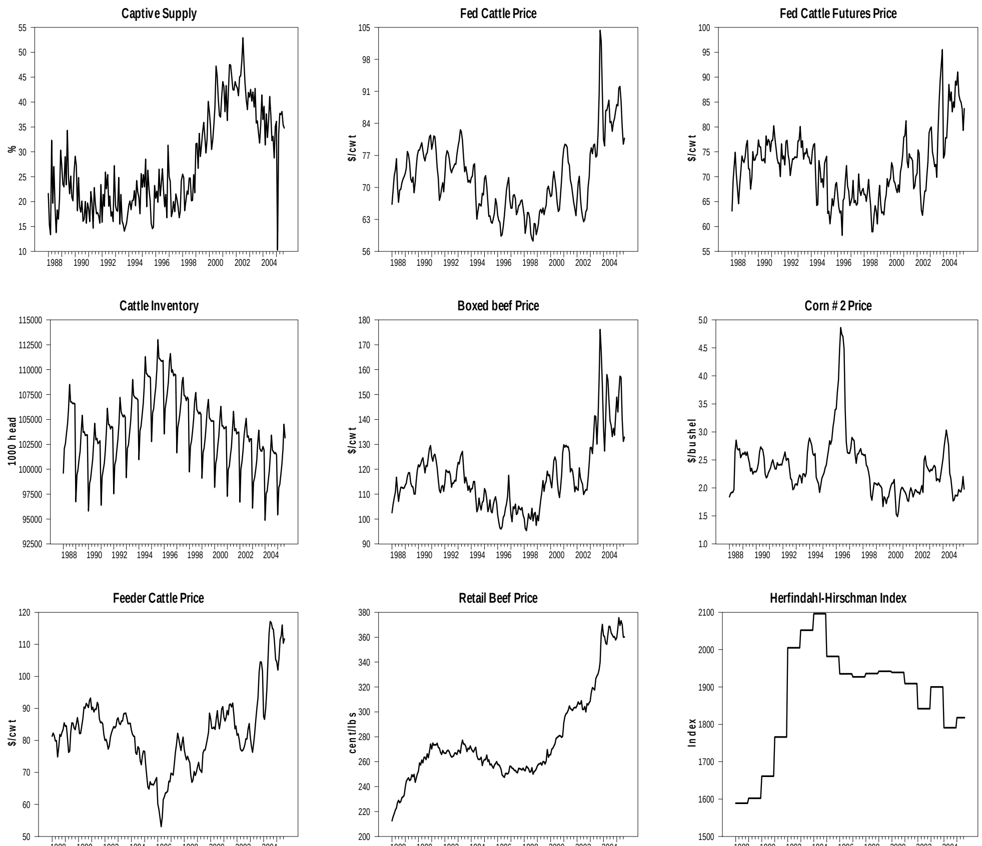


Figure 2.2. Nine important variables along the U.S. cattle supply chain (1988: 01 – 2005: 08)

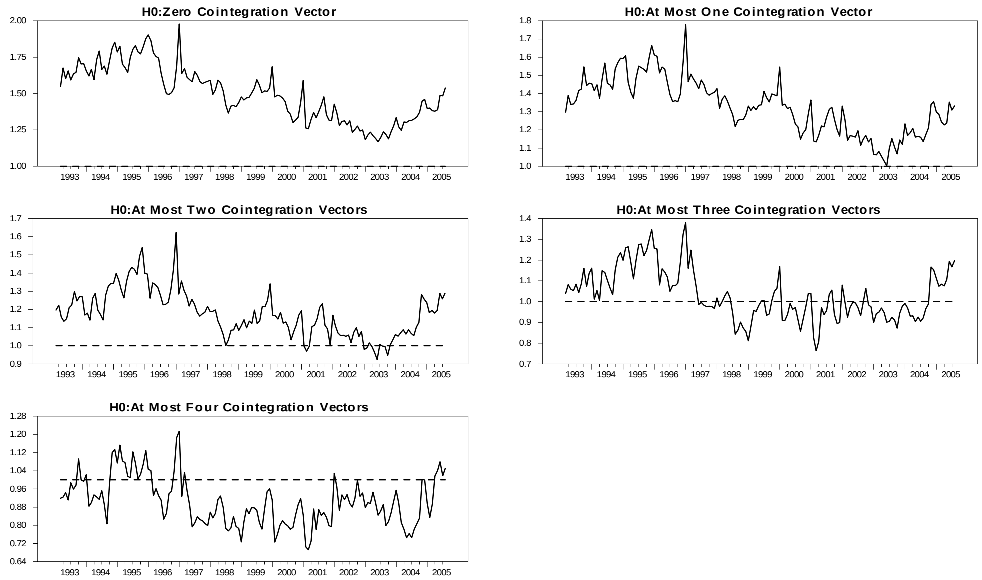


Figure 2.3. Normalized trace tests based on the rolling cointegration vectors (y-axis is the normalized test statistics)

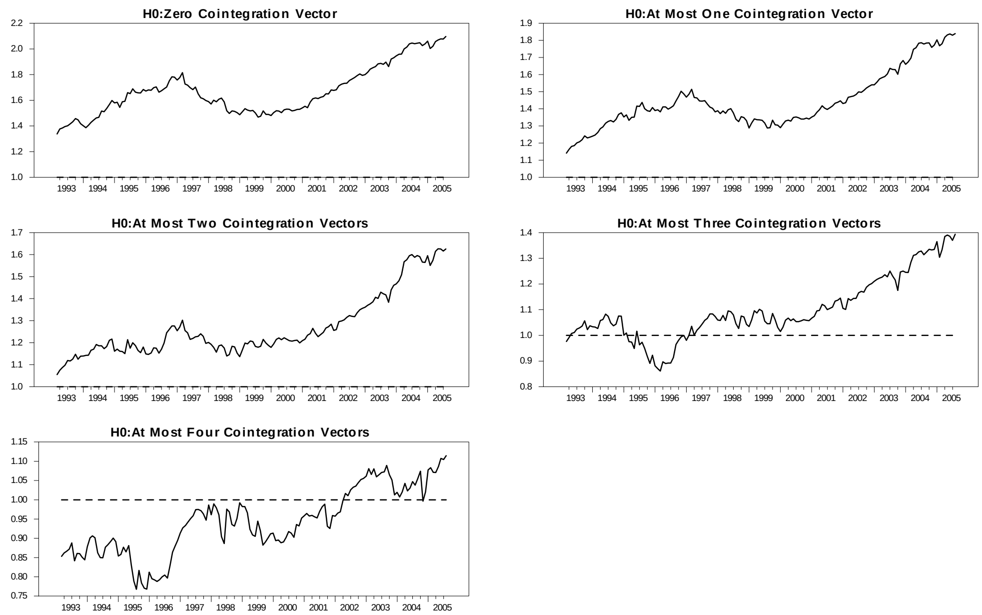
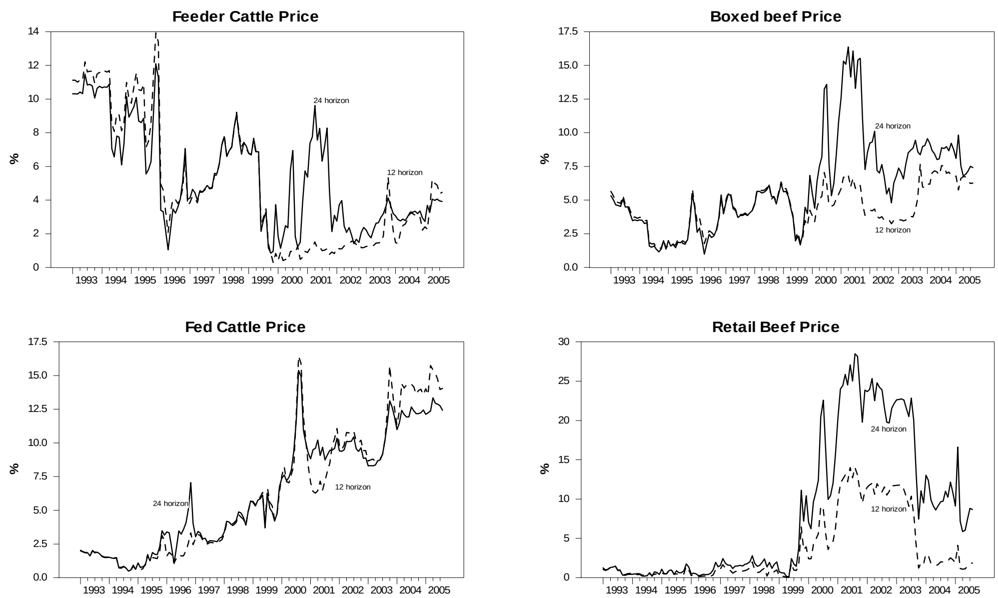
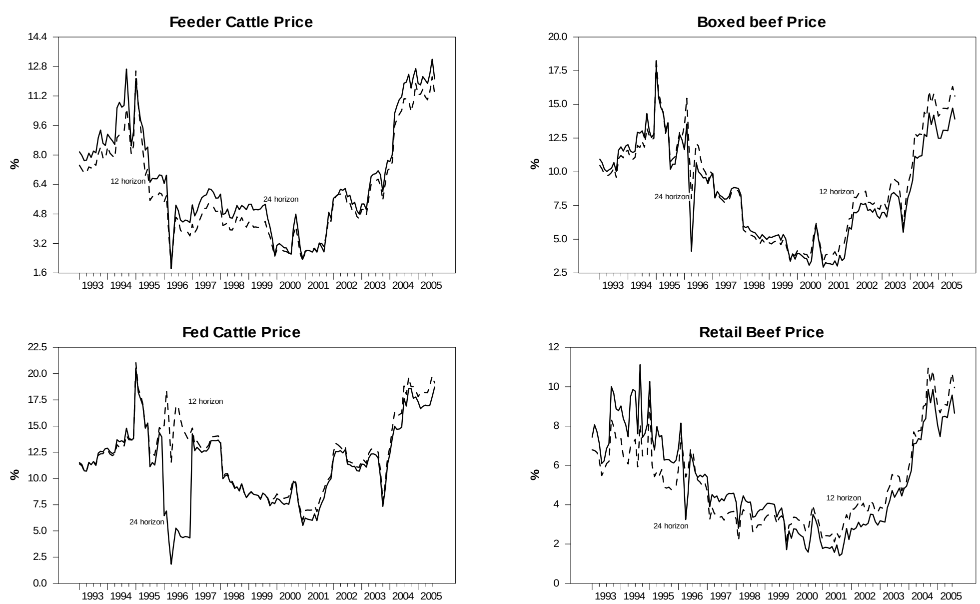


Figure 2.4. Normalized trace tests based on the recursive cointegration vectors (y-axis is the normalized test statistics)

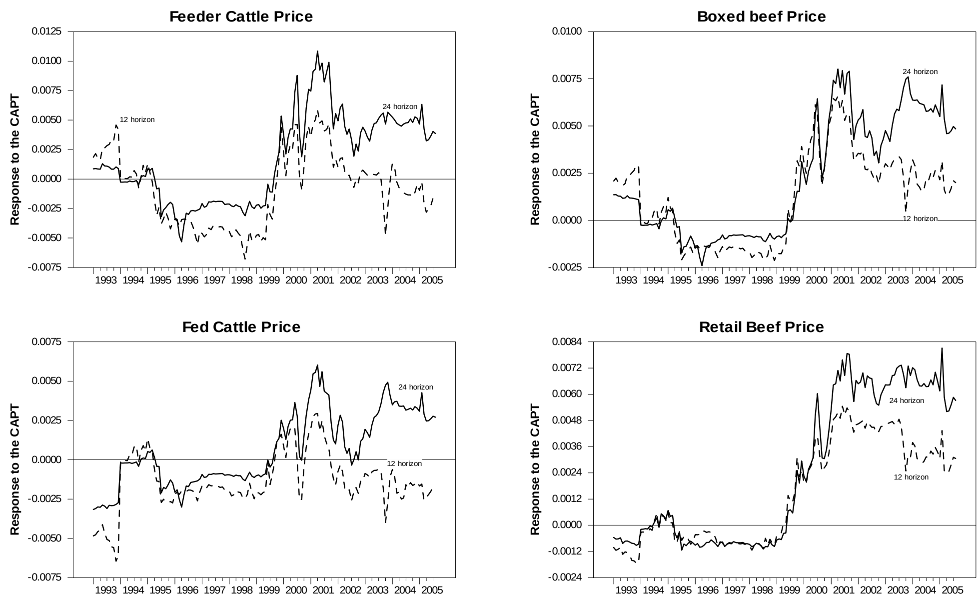


(1) Explained by captive supply

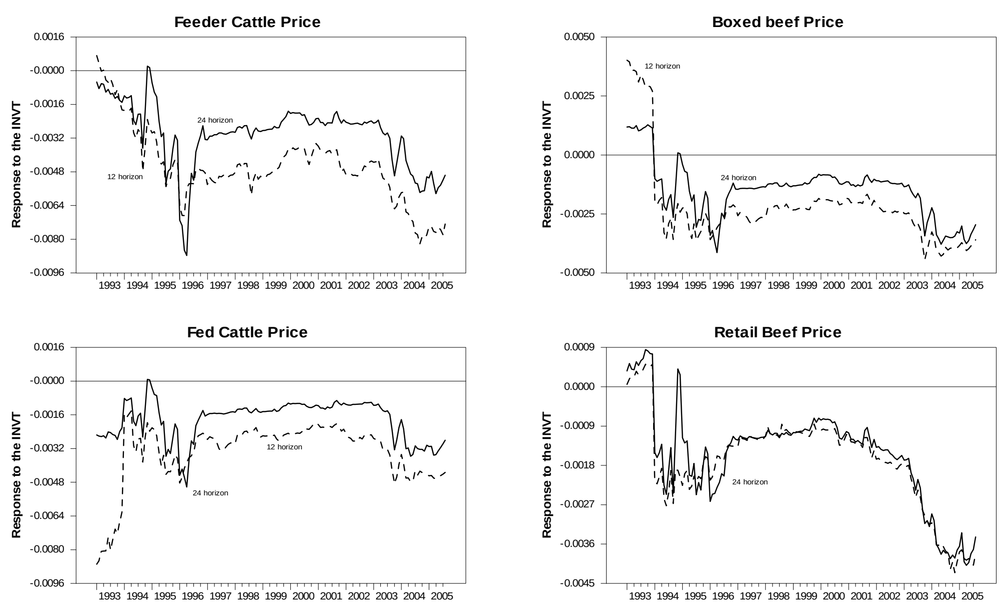


(2) Explained by cattle inventory

Figure 2.5. Recursive forecast error variance decomposition at the 12-month horizon (solid lines) and 24-month horizon (dashed lines)



(1) Impulse response to captive supply



(2) Impulse response to cattle inventory

Figure 2.6. Recursive impulse response functions at the 12-month horizon (solid lines) and 24-month horizon (dashed lines)

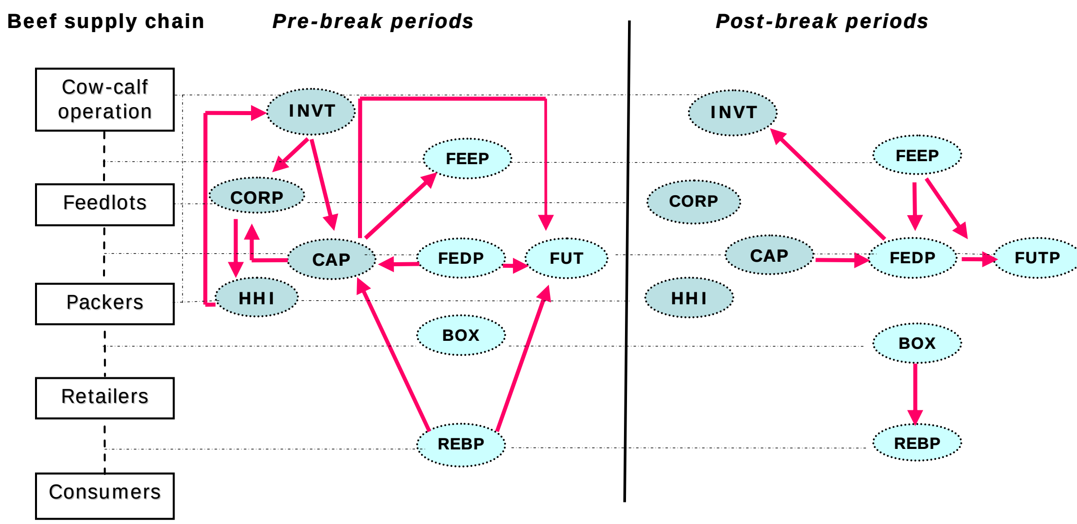


Figure 2.7. Out-of-sample temporal Granger causality

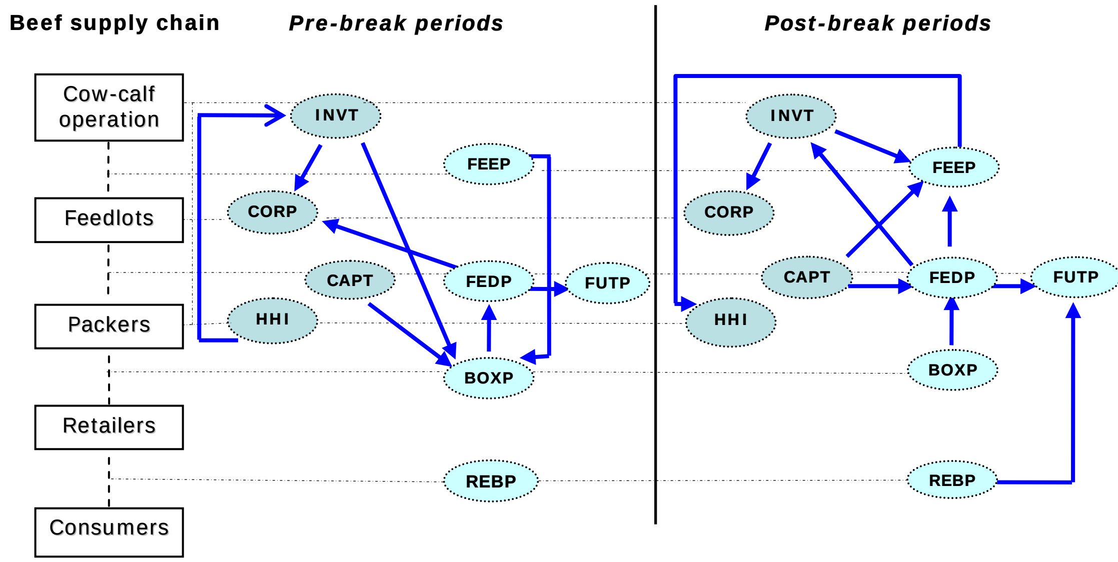


Figure 2.8. Contemporaneous DAGs causality

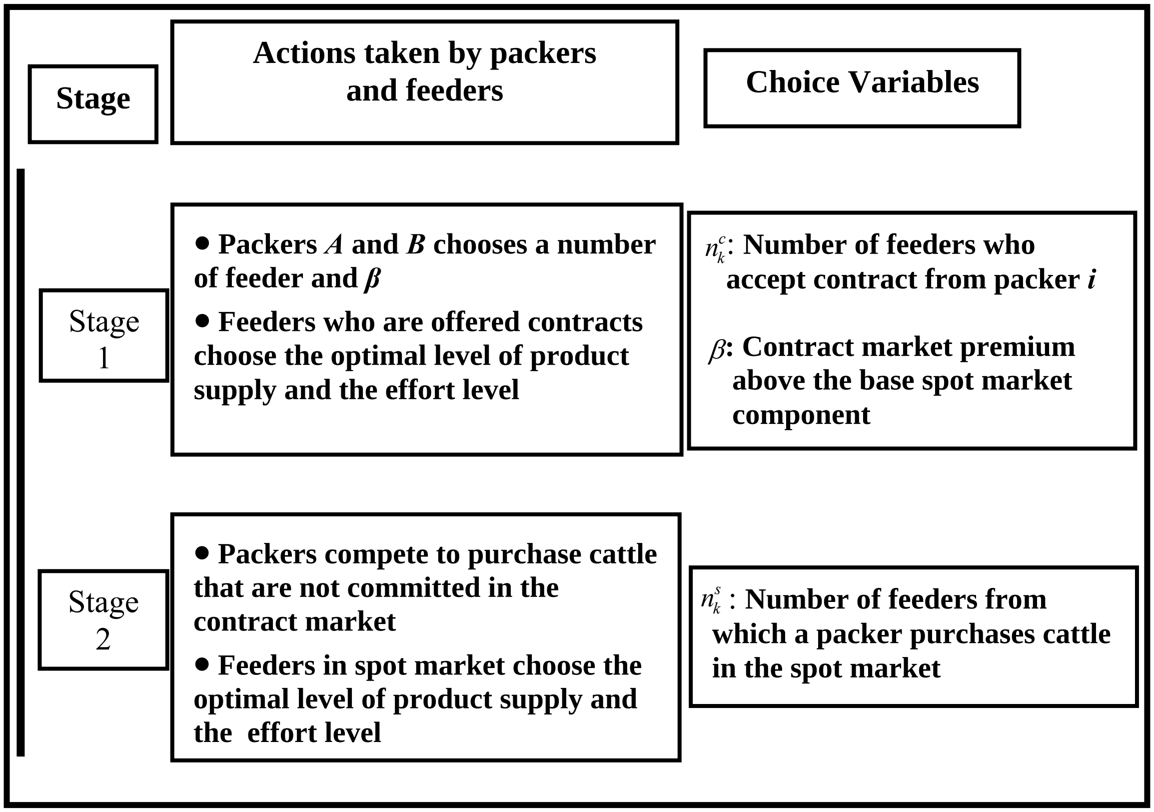
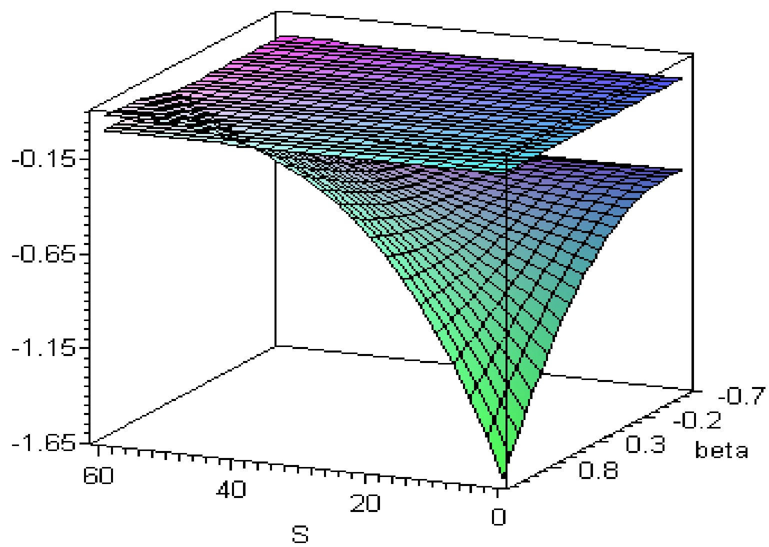
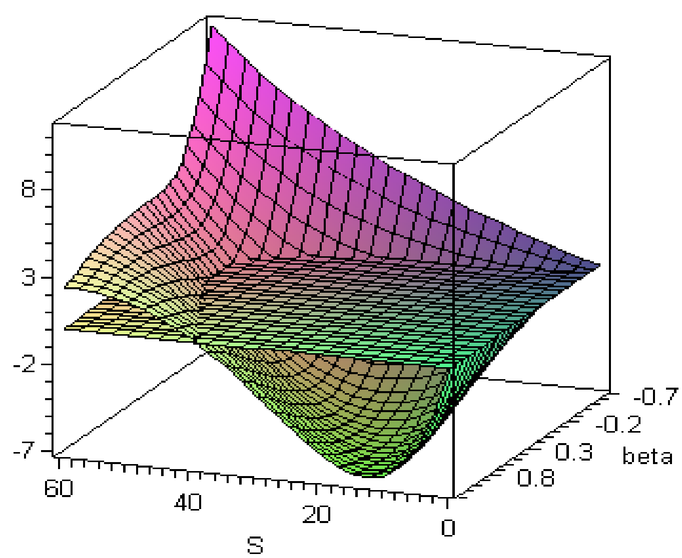


Figure 3.1. Actions and choices variable in the stage game



(a) 1st F.O.C



(b) 2nd F.O.C

Figure 3.2. Numerical results for first order condition

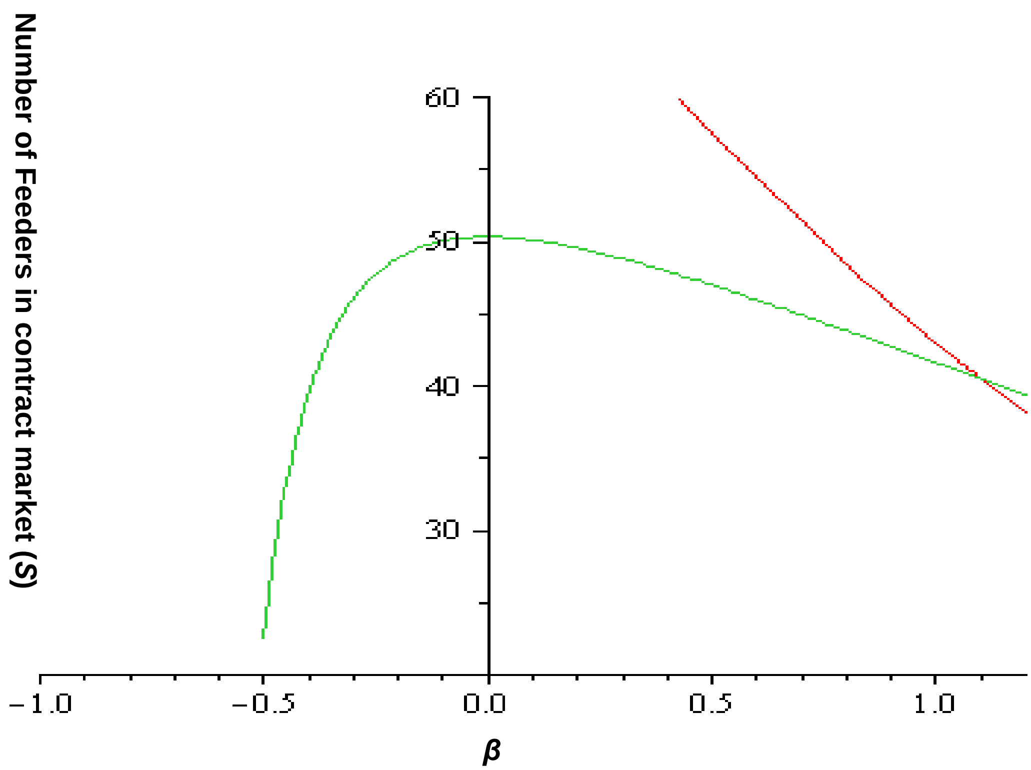
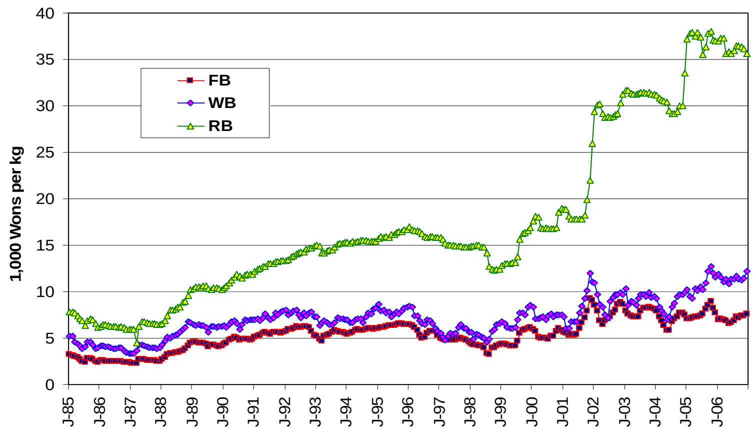
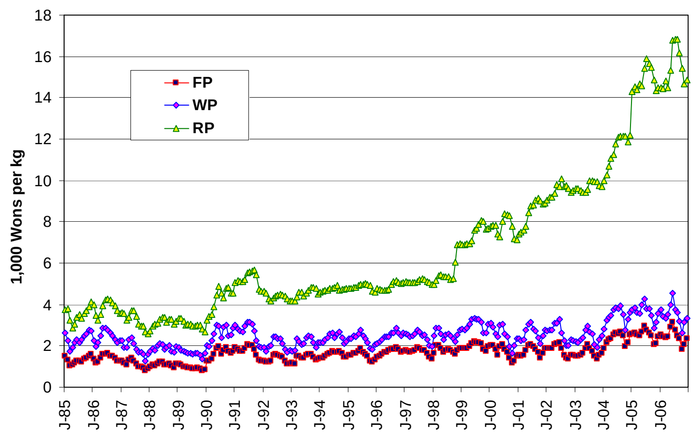


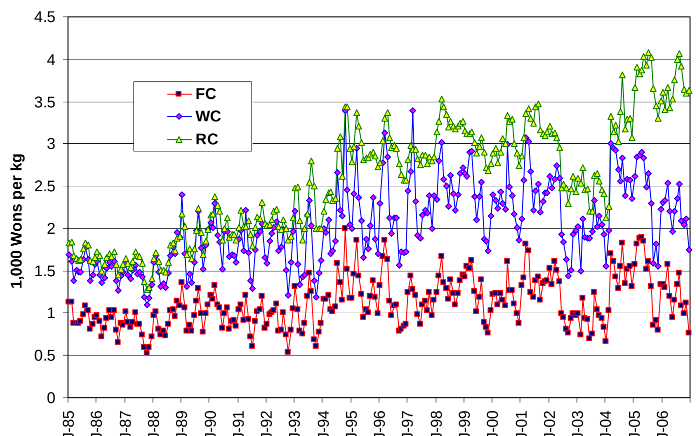
Figure 3.3. Numerical results for optimal *β* and *S*



(a) Beef



(b) Pork



(c) Chicken

Figure 4.1. Monthly prices of beef, pork, and chicken at the farm, wholesale, and retail levels (January 1985 -- December 2006)

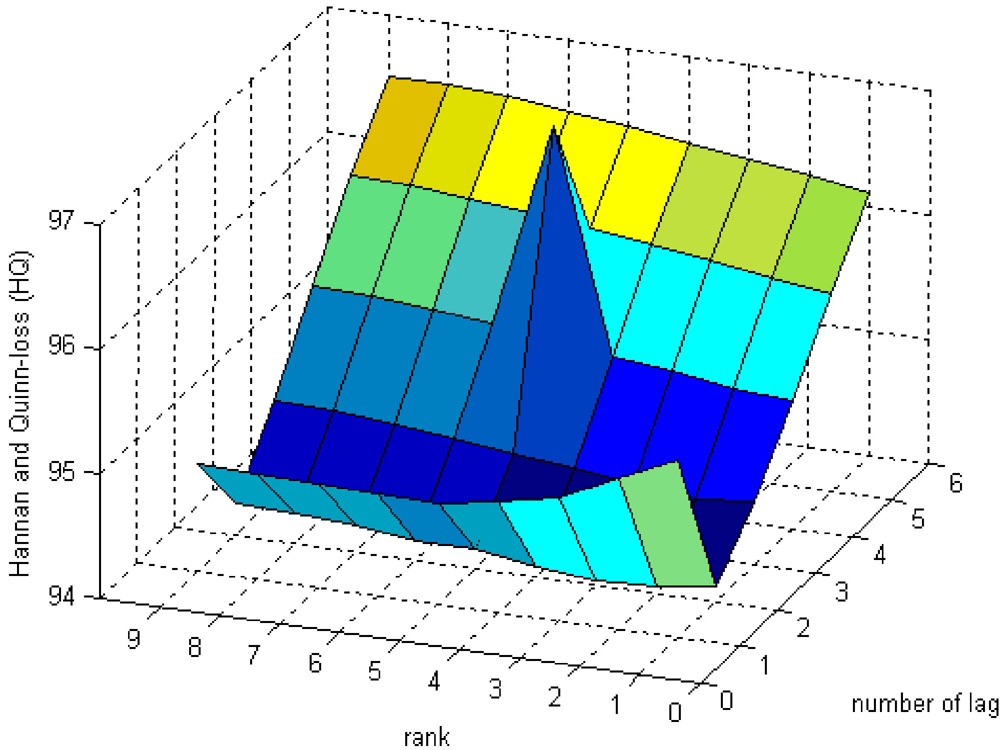
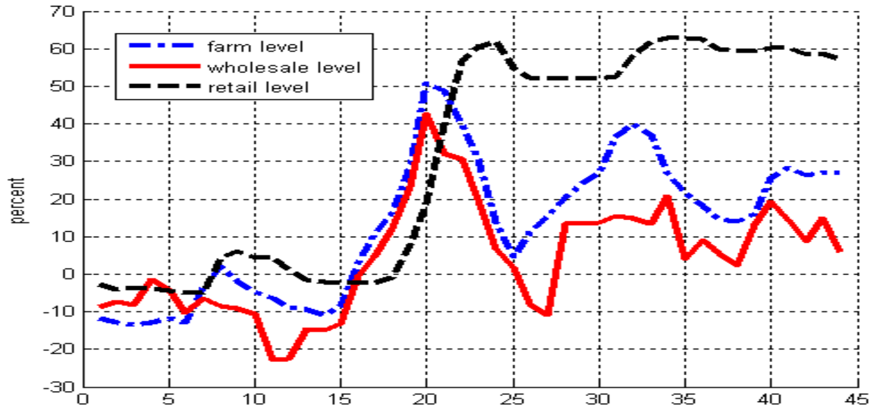
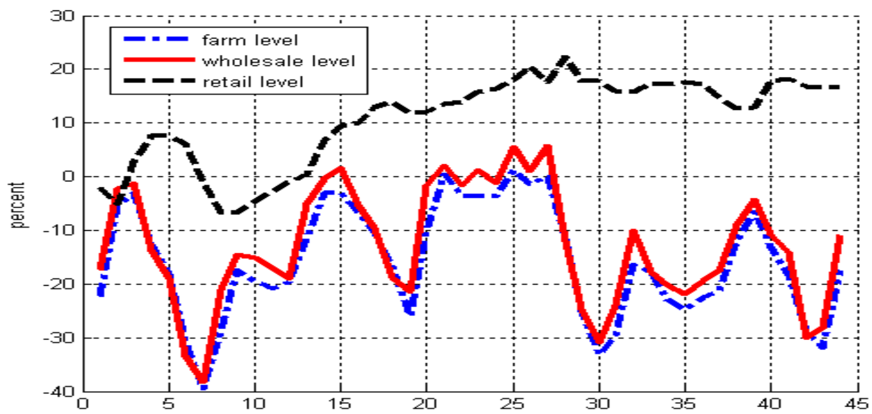


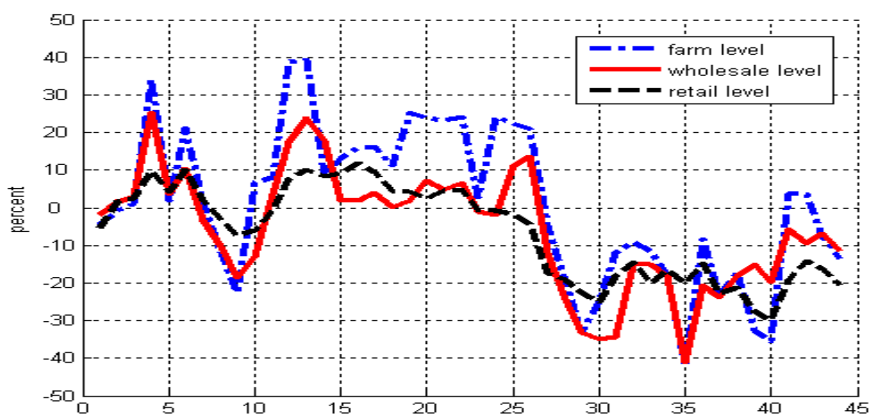
Figure 4.2. Hannan and Quinn (HQ) loss given different combinations of cointegration ranks (*r*) and lag length (*k*)



(a) Beef

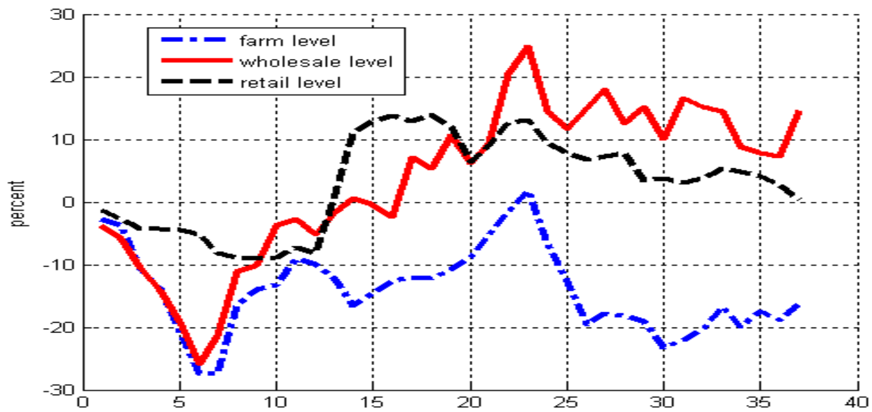


(b) Pork

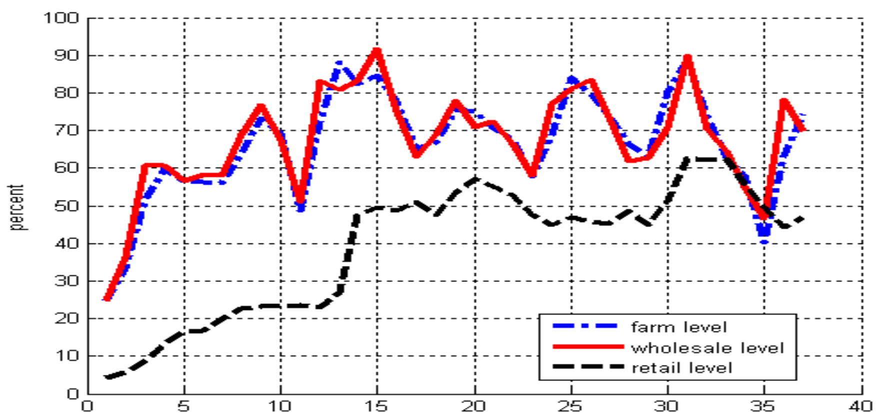


(c) Chicken

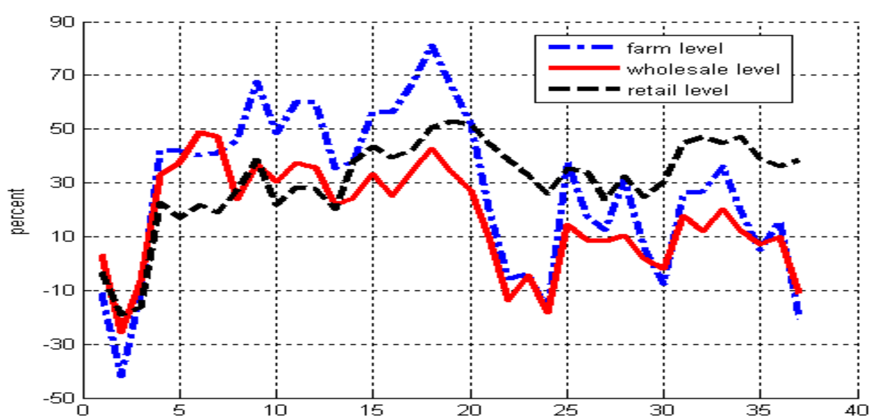
Figure 4.3. Percentage change of the actual price relative to the forecasted price following the FMD outbreak in April 2000 and before the AI/BSE incidents in December 2003 (The x-axis is the number of months after the 2000 FMD outbreak)



(a) Beef

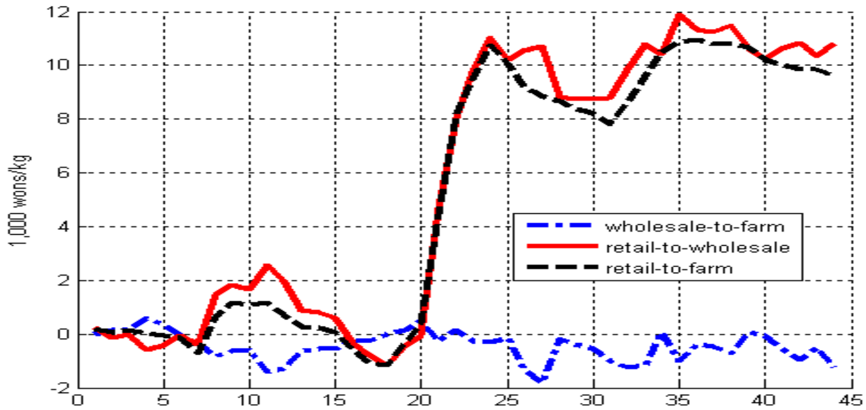


(b) Pork

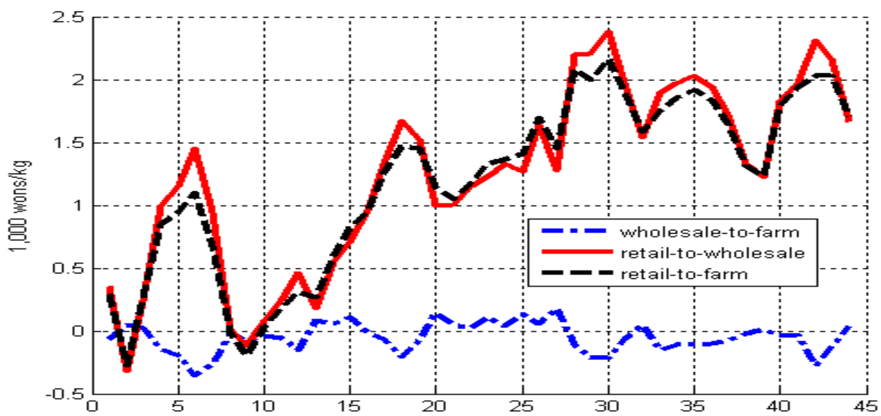


(c) Chicken

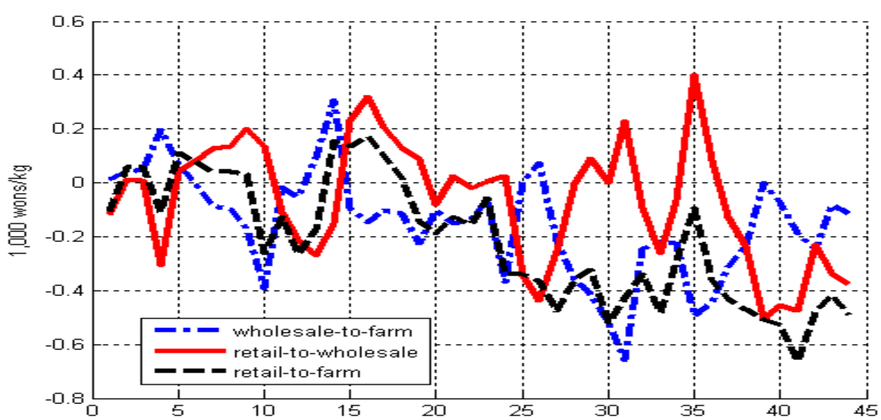
Figure 4.4. Percentage change of the actual price relative to the forecasted price following the AI/BSE incidents in December 2003 (The x-axis is the number of months after the incidents)



(a) Beef

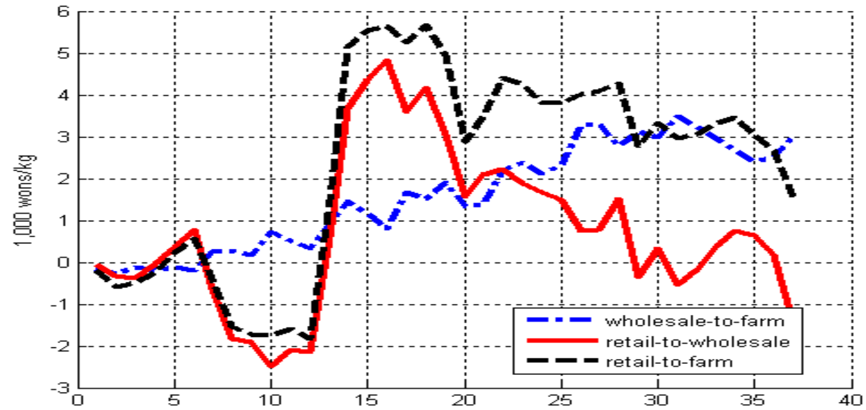


(b) Pork

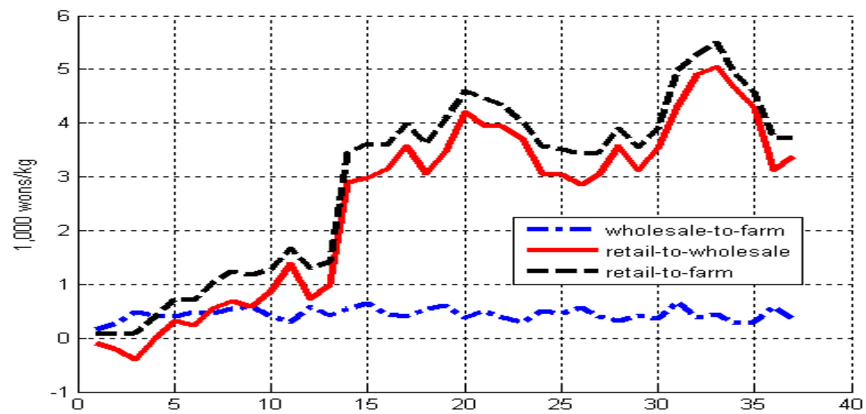


(c) Chicken

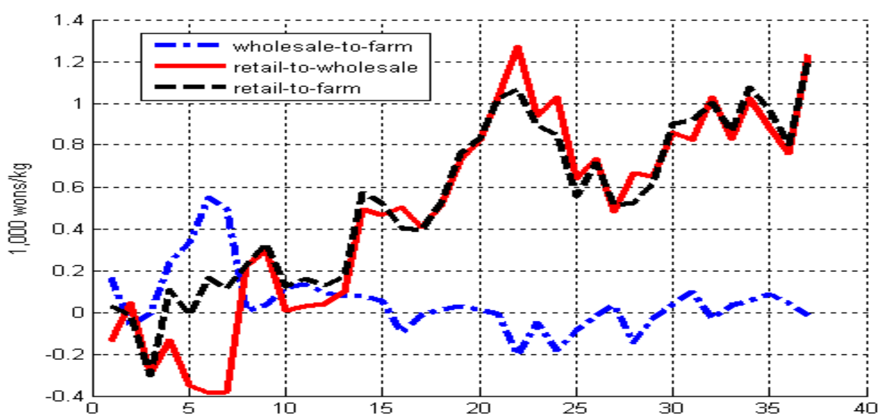
Figure 4.5. Changes in the price margin along the supply chain following the FMD outbreak in April 2000 and before the BSE/AI incidents in December 2003 (The x-axis is the number of month after the event)



(a) Beef



(b) Pork



(c) Chicken

Figure 4.6. 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)

$$
\begin{array}{ccccccccc} FB & FP & FC & WB & WP & WC & RB & RP & RC \end{array}
$$

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

Figure 4.7. Correlation matrix of the innovations ($\hat{e}$) estimated from the ECM

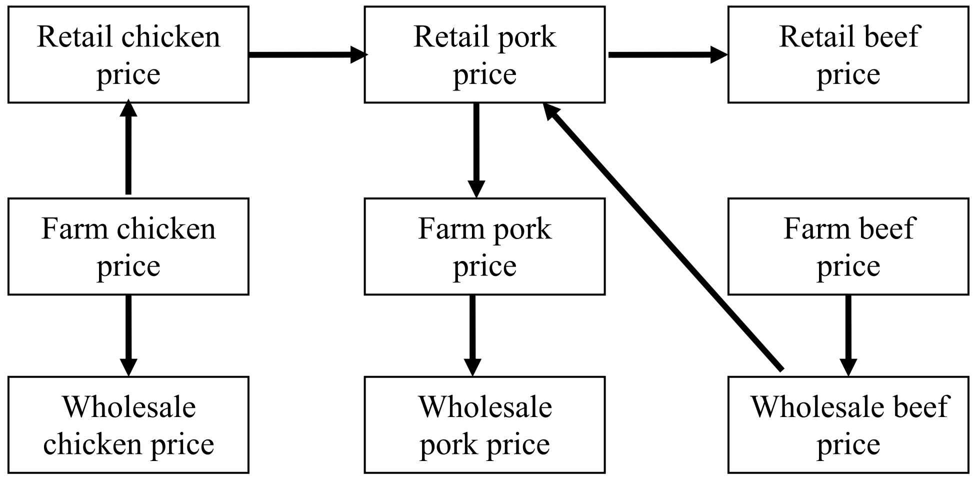
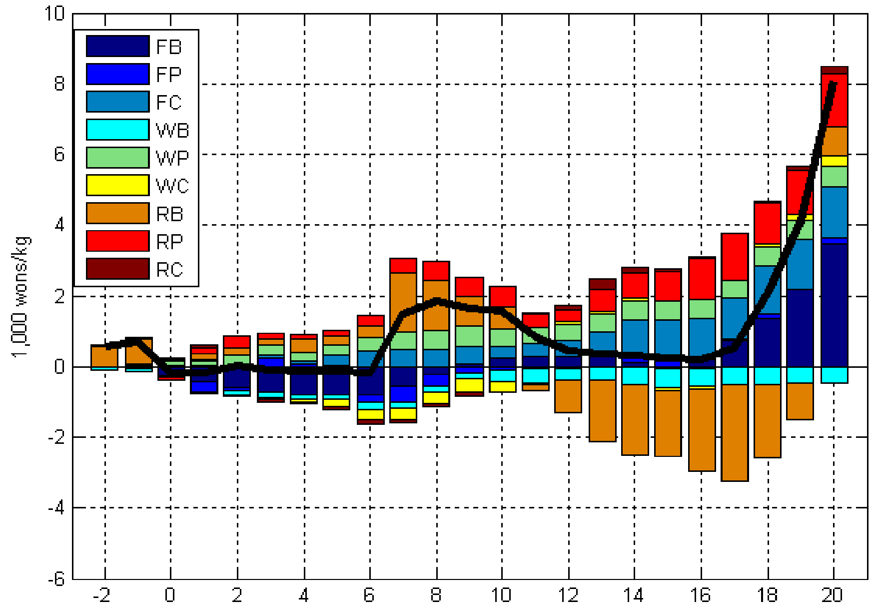
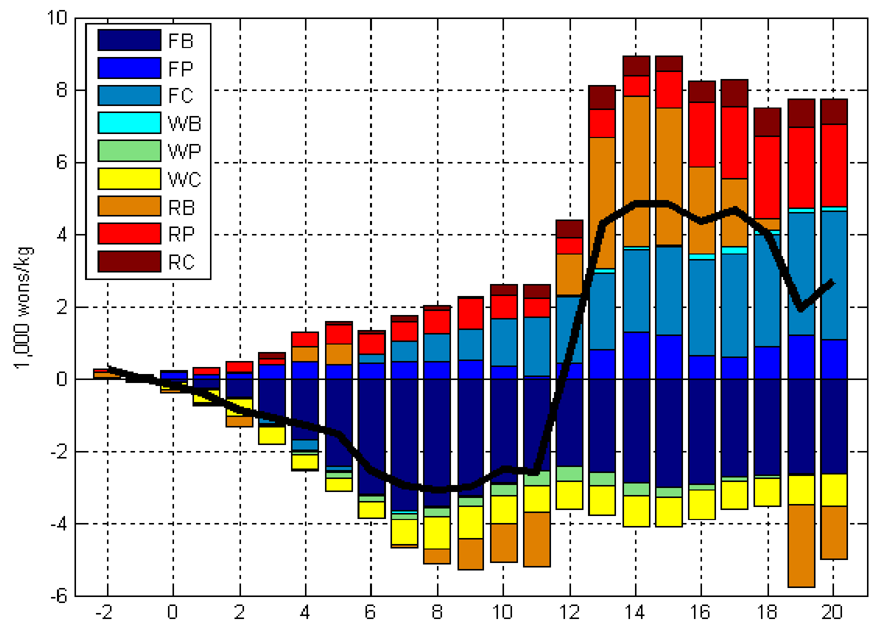


Figure 4.8. DAG results based on the GES algorithm



(a) Responding to the 2000 FMD outbreak



(b) Responding to 2003 AI/BSE incidents

Figure 4.9. 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)

APPENDIX C

TABLES

Table 2.1. Contemporaneous Innovation Correlation Matrix

Pre-Break Periods

$\Omega_1 =$

	CAPT	INVT	FEEP	FEDP	BOXP	REBP	FUTP	CORP	HHI
CAPT	1.000								
INVT	-0.086	1.000							
FEEP	-0.100	0.177	1.000						
FEDP	-0.298	-0.255	0.543	1.000					
BOXP	-0.287	-0.205	0.567	0.871	1.000				
REBP	-0.033	-0.083	-0.068	0.021	0.054	1.000			
FUTP	-0.172	-0.222	0.333	0.561	0.420	0.028	1.000		
CORP	0.070	-0.133	-0.287	-0.287	-0.190	0.093	-0.110	1.000	
HHI	-0.022	-0.427	-0.030	0.093	0.050	-0.048	0.005	0.048	1.000

Post-Break Periods

$\Omega_2 =$

	CAPT	INVT	FEEP	FEDP	BOXP	REBP	FUTP	CORP	HHI
CAPT	1.000								
INVT	-0.058	1.000							
FEEP	0.118	0.235	1.000						
FEDP	-0.259	-0.335	0.328	1.000					
BOXP	-0.027	-0.332	0.289	0.772	1.000				
REBP	0.004	-0.184	-0.062	0.114	0.053	1.000			
FUTP	-0.157	-0.174	0.246	0.521	0.355	0.445	1.000		
CORP	-0.116	-0.247	-0.187	0.114	-0.038	-0.043	0.128	1.000	
HHI	0.025	0.232	0.320	0.148	0.176	0.004	0.228	-0.095	1.000

Table 2.2. Out-of-Sample Temporal Granger Causality Test

Pre-break periods

	CAPT	*INVT*	*FEEP*	*FEDP*	*BOXP*	*REBP*	*FUTP*	*CORP*	*HHI*
CAPT	–	0.474**		0.752**		0.535**			
INVT		–		-0.755	-0.796				0.499**
FEEP	0.742**		–	-0.678	-0.751		-1.945	-1.464	
FEDP		-0.850	-0.504	–		-1.511			0.039
BOXP		-0.623	-0.365		–	-0.623	-1.369	0.66	
REBP				-1.169	-1.223	–			
FUTP	1.341**		-0.309	1.650**	-0.306	0.568**	–	0.126	0.0143
CORP	0.695**	0.810**	-0.506					–	
HHI								0.885**	–

Post-break periods

	CAPT	*INVT*	*FEEP*	*FEDP*	*BOXP*	*REBP*	*FUTP*	*CORP*	*HHI*
CAPT	–								
INVT	0.041	–		0.097*			-0.101	-0.060	
FEEP		-0.051	–		-0.186		0.033		
FEDP	0.332*	-0.047	0.325*	–		-0.006		-0.009	0.020
BOXP	0.002	-0.144		0.008	–	-0.034		-0.005	0.016
REBP	0.065		-0.069		0.153*	–		-0.025	0.009
FUTP			0.129*	0.164*			–		
CORP								–	
HHI									–

Note: No entry on any off-diagonal cell represents cases that an unrestricted model has a larger MSFE than a restricted model. The null hypothesis is that each series in the first row does not Granger cause any particular series in the first column. The critical values (MSE-T test) of DM test given in Clark and McCracken (2001), corresponding to $k_2 = 9$ (the number of variables in the unrestricted model), and $\pi = P / R = 0.6$ where P is the number of forecasts and R is base sample period to calculate the first forecast, are 0.397 at the 95% confidence level and 0.096 at 90% confidence level. Asterisks, **and *, indicate that the null is rejected at the 5% and 10% significance level, respectively.

Table 3.1. Comparative Static Results: Spot Market

	$E(W_k^s)$	X^s	$x_k^s = x^s$ for any k	$e_k^s = e^s$ for any k	$E(p^s)$
$\tilde{p}$	$\frac{2(1+\gamma\sigma_{\mathbf{z}}^2)}{\Delta}\Omega$	$\frac{(N-S)}{\Delta}\Omega$	$\frac{2}{\Delta}\Omega$	$\frac{2\delta}{\Delta}\Omega$	$1+\frac{2\delta^2}{\Delta}\Omega$
δ	$\frac{4\tilde{p}\delta(1+\gamma\sigma_{\mathbf{z}}^2)}{\Delta^2}\Omega$	$\frac{2\tilde{p}\delta(N-S)}{\Delta^2}\Omega$	$\frac{4\tilde{p}\delta}{\Delta^2}\Omega$	$\frac{2\tilde{p}((1+\gamma\sigma_{\mathbf{z}}^2)+\delta^2)}{\Delta^2}\Omega$	$\frac{4\tilde{p}\delta(1+\gamma\sigma^2)}{\Delta^2}\Omega$
γ	$-\frac{2\tilde{p}\delta^2\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$	$-\frac{\tilde{p}\sigma_{\mathbf{z}}^2(N-S)}{\Delta^2}\Omega$	$-\frac{2\tilde{p}\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$	$-\frac{2\tilde{p}\delta\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$	$-\frac{2\tilde{p}\delta^2\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$
σ^2	$-\frac{2\tilde{p}\delta^2}{\Delta^2}\Omega$	$-\frac{\tilde{p}\gamma(N-S)}{\Delta^2}\Omega$	$-\frac{2\tilde{p}\gamma}{\Delta^2}\Omega$	$-\frac{2\tilde{p}\delta\gamma}{\Delta^2}\Omega$	$-\frac{2\tilde{p}\delta^2\gamma}{\Delta^2}\Omega$

Where $\Delta = (1+\gamma\sigma_{\mathbf{z}}^2) - \delta^2$, $\Omega = \left(\frac{(N-S)}{3(N-S)+(1+\beta^2)S}\right)$

Table 3.2. Comparative Static Results: Contract Market

	$E\left(W_k^c\right)$	X^c	$x_k^c = x^c$ for any k	$e_k^c = e^c$ for any k	$E\left(p^c\right)$
$\tilde{p}$	$\frac{2(1+\beta)\left(1+\gamma\sigma_{\mathbf{z}}^2\right)\Omega}{\Delta}$	$\frac{(1+\beta)(N-S)}{\Delta}\Omega$	$\frac{2(1+\beta)}{\Delta}\Omega$	$\frac{2(1+\beta)\delta}{\Delta}\Omega$	$1+\frac{2(1+\beta)\delta^2}{\Delta}\Omega$
δ	$\frac{4(1+\beta)\tilde{p}\delta\left(1+\gamma\sigma_{\mathbf{z}}^2\right)}{\Delta^2}\Omega$	$\frac{2(1+\beta)\tilde{p}\delta(N-S)}{\Delta^2}\Omega$	$\frac{4(1+\beta)\tilde{p}\delta}{\Delta^2}\Omega$	$\frac{2(1+\beta)\tilde{p}\left(\left(1+\gamma\sigma_{\mathbf{z}}^2\right)+\delta^2\right)}{\Delta^2}\Omega$	$\frac{4(1+\beta)\tilde{p}\delta\left(1+\gamma\sigma^2\right)}{\Delta^2}\Omega$
γ	$-\frac{2(1+\beta)\tilde{p}\delta^2\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$	$-\frac{(1+\beta)\tilde{p}\sigma_{\mathbf{z}}^2(N-S)}{\Delta^2}\Omega$	$-\frac{2(1+\beta)\tilde{p}\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$	$-\frac{2(1+\beta)\tilde{p}\delta\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$	$-\frac{2(1+\beta)\tilde{p}\delta^2\sigma_{\mathbf{z}}^2}{\Delta^2}\Omega$
σ	$-\frac{2(1+\beta)\tilde{p}\delta^2}{\Delta^2}\Omega$	$-\frac{(1+\beta)\tilde{p}\gamma(N-S)}{\Delta^2}\Omega$	$-\frac{2(1+\beta)\tilde{p}\gamma}{\Delta^2}\Omega$	$-\frac{2(1+\beta)\tilde{p}\delta\gamma}{\Delta^2}\Omega$	$-\frac{2(1+\beta)\tilde{p}\delta^2\gamma}{\Delta^2}\Omega$

Where $\Delta = \left(1+\gamma\sigma_{\mathbf{z}}^2\right) - \delta^2$, $\Omega = \left(\frac{(N-S)}{3(N-S)+(1+\beta^2)S}\right)$

Table 4.1. 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 4.2. 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

Note: 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 4.3. 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 C.2 for Critical value* and Table C.3 for Critical Value. R and F stand for “reject the null hypothesis” and “fail to reject the null hypothesis”, respectively.

VITA

Name: Moon-Soo Park

Address: 103-706 Kum-Ho APT, Ochi-dong, Buk-Gu, GwangJu, Korea

Email: mspark9497@gmail.com

Education: Ph.D. in Agricultural Economics 2008
Texas A&M University

B.S. in Economics 1994
Chonnam National University

Fields:

Applied Microeconomics, Applied Econometrics, Bio- Security

Publications:

Park, M.S., Y.H. Jin, and H. A. Love, 2008. “Causality and Structural Break in US Cattle Supply Chain.” Working paper.

Park, M.S., Y.H. Jin, and D. A. Bessler, 2008. “The impact of Animal Disease Crises on the Korean Meat Market.” Working paper.