Modelling Market Linkages along the Vertical Supply Chain: Price Transmission and Volatility Spillovers in the U.S. Pork Industry

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Abstract

This paper assesses the linkages among farm, wholesale and retail markets along the U.S. pork supply chain by analyzing their price transmissions and volatility spillovers. Data used in the analysis include monthly farm, wholesale and retail price for pork, covering the period of January 2000 through December 2014. Engle and Grager's cointegration technique was adopted to examine long run price relationships for each pair of markets, while an asymmetric VAR-BEKK-GARCH model was followed to investigate whether asymmetry plays a role in short-run price adjustments and volatility spillovers.

Key findings of this study include: (1) the presence of long-run relationship in all three pairs of markets; (2) asymmetric short-run price adjustments in retail and farm markets; (3) asymmetry in wholesale price volatility, wholesale price will be more volatile when confront with positive shocks; (4) bi-directional volatility spillovers in all three pairs of markets; and (5) asymmetric spillover effects to wholesale and farm markets, with price instabilities being more sensitive to the joint shocks that move in different directions.

Key Words: asymmetry, price transmission, vertical supply chain, asymmetric VAR-BEKK-GARCH, volatility spillover, U.S. pork industry

1. Introduction

Since 1970s the U.S. pork industry has undergone a number of mergers and consolidations at all levels of markets along the vertical chain, leading to numerous studies conducted to investigate the linkages among farm, wholesale and retail meat prices. Among the large body of studies, the analysis is often related to the detection of asymmetries between upstream and downstream markets to examine whether a particular group has the power to asymmetrically influence price level transmissions (e.g., Miller and Hayenga, 2001; Gervais, 2011). More recently, the investigation of volatility spillovers has gained increasing popularity (e.g., Lahiani et al., 2013; Rezitis and Stavropoulus, 2011; Serra and Gil, 2013). On one hand, price volatilities upstream might expose the downstream sector to sourcing uncertainties, forcing food and agricultural companies to alter their sourcing strategies (Rabobank, 2011). On the other hand, agents in the upstream sector may react to the downstream instabilities by reducing output supply and investments in productive inputs (Sckokai and Moro, 2009). Therefore, an understanding of volatility interactions can provide better insights into risk management strategies and decision makings. Because price instabilities can expose farmers to sourcing uncertainties and consumers to food security risks (Assefa at al., 2015), the examination of volatility spillovers would also shed lights on welfare and policy ramifications.

The present paper contributes to the literature on price transmissions by providing analyses on both asymmetric price and price volatility transmissions. Even though vertical price linkages regarding meat markets have been extensively studied in the literature (e.g., Lloyd et al., 2006; Uchezuba et al., 2010; Serra, 2011; Ozertan et al., 2015), many of the existing studies only focus on the transmission of price levels and shocks using cointegration and vector autoregressive models or vector error correction models (e.g., Goodwin and Harper, 2000; Rojas et al., 2008;

Boetel and Liu, 2010). Little attention is given to the examination of volatility transmissions within the chain, and studies that simultaneously examine both are even more limited with most of them cater to the analysis of financial markets (e.g., Gomes and Chaibi, 2014; Qiao et al., 2008; Rajhans and Jain, 2015). Additionally, many studies regarding price volatilities neglect the fact that positive and negative shocks may lead to different impacts on price volatilities and volatility transmissions.

The objective of this study is to investigate the U.S. pork price linkages by examining the extents of price transmissions and volatility spillovers along the supply chain. Specifically, price transmission elasticities, extent of price adjustments and the degree to which volatility in one market spills over into other markets are assessed. To fill in the gap that fewer existing studies account for the differential impacts of positive and negative market shocks, asymmetry is examined by assessing whether: 1) positive and negative cumulative effects of lagged price changes are the same or not; 2) spillover effects caused by positive and negative market shocks are of the same degree or not.

The remainder of this paper proceeds as follows. Section 2 reviews the structural changes of the industry and the time series techniques used for the analysis of vertical price linkages. Section 3 presents the data base, and empirical procedures are introduced in Section 4. Section 5 describes the empirical results and discussions. Conclusions are drawn by section 6.

2. Background

2.1. The U.S. pork industry

The U.S. pork industry has seen dramatic changes at all levels of markets over the last several decades. At the farm level, hog production has become increasingly concentrated and specialized. Farms have moved away from the traditional farrow-to-finish operations to specialization in a single phase of production. In 2008, specialized operations account for about 77 percent of the nation's hog production (Lowe and Gereffi, 2008). For the processing market, concentration has been accompanied by increasing packer ownership of livestock (Starmer and Wise 2007). In 2007, the top four hog packing companies (i.e., Smithfield Foods, Tyson, JBS, and Cargill) controls 67% of the U.S. hog processing market (GAO, 2009; Smithfield Foods, 2010). Market consolidations strengthened by the rise of supercenters have been pervaded at the retail level. On the other hand, vertical integration (e.g., wholesalers' involvement in further processing activities) and the use of production and marketing contracts have become the key trends to organize exchange across the stages of the market chain. By 2008 only about 10 percent of hogs were procured through negotiated cash contracts. Current percentages are even lower in the range of 3 to 5 percent (Saitone and Sexton. 2012).

In December 1998, farm-level price in the U.S. reached a historical low, but analogous price changes were not observed at the wholesale and retail levels. Many involved agents, especially producers and consumers, started questioning the extent to which concentration, consolidation, and vertical integration may have been related to this event (Goodwin and Harper, 2000). In well-functioning (integrated) markets price shocks in any market level are transmitted to other market levels; primary producers benefit from price increases at the wholesale and retail levels and final consumers benefit from the cost reductions upstream. However, with the dramatic structural changes producers and consumers are worried they may not benefit from those favorable price changes. Given the associated price changes in other markets, farm prices might fall more quickly than they rise and retail prices might rise faster than they fall (Miller and Hayenga, 2001). In other words, there might be inequalities in price transmissions along the chain.

2.2. Literature Review on the Techniques for Price Transmission Analysis

To address the concerns held by the involved agents, a wide variety of empirical studies have focused on the detection of asymmetric price transmissions. The standard approach to test for asymmetries was first developed by Wolffram (1971), and has been widely employed in the agricultural economics literature. The model specifies the regression of differenced price as a function of positive and negative price variations over time, and this model is generally known as the Vector Autoregressive model (VAR). Von Cramon-Taubadel (1998) further extended the model to a linear error correction model (ECM) by including an error correction term to explain price changes in the short run drift back to a stable long-run equilibrium. Recently, threshold cointegration model has been adopted extensively (e.g., Goodwin and Holt, 1999; Hassouneh et al., 2010; Simioni et al., 2013). This model does not only take care of the possibility of nonlinear and threshold-type adjustments in the price series. However, unlike the asymmetric VAR model, threshold model is constrained by the assumption of constant variance. Reviews of the previous literature for asymmetric price transmissions have been made by von Cramon-Taubadel and Meyer (2004) and Frey and Manera (2007).

The primal methodology to analyze price volatilities and the associated spillovers is the General AutoRegressive Conditional Heteroskedasticity (GARCH) model. It was first introduced by Engle (1982) and modified by other researchers such as Nelson (1991) and Engle and Kroner (1995) later on. GARCH model is empirically favorable because it can capture the dynamic structures of conditional variance, incorporate heteroscedasticity into the estimation procedure, and allow for simultaneous estimation of several parameters (Chou, 1988). As for the scarce literature focusing on meat price volatility transmissions, Buguk et al. (2003) employed an EGARCH model to test the univariate spillover for prices in the U.S. catfish supply chain. They found strong volatility spillover from feeding material to catfish feed and farm- and wholesale-level catfish prices. Uchezuba et al. (2010) adopted the same model for the South African broiler market and also detected unidirectional volatility spillover from the farm to retail levels of the value chain. Khiyavi et al. (2012) investigated the volatility spillover effects across input prices, producer and retail levels in Iran poultry market using VECH-GARCH model. The empirical findings showed the volatility of input and retail prices exerts positive spillover effects on the producer price. Comprehensive literature reviews regarding price volatility transmission in food supply chains can be found in Assefa et al. (2015).

3. Data

This study uses three series (i.e. farm, wholesale, retail levels) of monthly pork prices from January 1970 to December 2014 (540 observations). Data is collected from the Economic Research Service of the United States Department of Agriculture (ERS-USDA 2015). The farm price is in net value, which equals to the subtraction of byproducts value from the AMS 51%-52% base-lean-hog price. Wholesale price is the average value of the meat as it leaves the packing plant. While retail price is a weighted average of the retail prices for specific pork parts as reported by the Bureau of Labor Statistics (BLS-USDA). To remove the impacts of inflation, all price series are deflated to real levels using Consumer Price Index (CPI) in 2010 (FRED 2015) as the base and transformed in logarithms.

[Figure is 1 about here]

Figure 1 presents the plot of U.S. monthly pork prices and price changes at three market levels. The visual inspection exhibits several patterns. First, three price series tend to move together from 1970 to mid-1980s. After then, retail price diverges from the other two series and only the farm-wholesale pair shows strong price co-movements. Second, farm and wholesale price series display a decreasing trend until mid-2000s and keep relatively constant in the recent years. Retail price seems to be constant all over the time. Third, farm price seems to be the most volatile price series while retail price is the least volatile one. At last, farm price hits the historical minimum in December 1998, as well-known as the "hog crisis," and increases significantly right after the crisis. However, no big changes are observed for retail and wholesale prices during that time.

Before establishing price transmission models, we need firstly check the stationarity of the price series. Three tests (standard ADF test (Dickey and Fuller, 1979), PP test (Philipps and Perron, 1988) and KPSS test (Kwiatkowski et al., 1992)) are conducted to ensure the models' appropriateness. Lag selections for these tests are based on Bayesian Information Criterion (BIC). The results (Table 1) reveal KPSS test rejects the stationarity null, and ADF and PP tests fail to reject the unit root hypothesis. Thus, unit-roots are present in all three price series. After differencing the price series, we run the tests again. The results show ADF and PP tests reject the unit root null, while KPSS test fails to reject the stationarity hypothesis. Because all differenced series are stationary, price series at three market levels are I (1). The distribution characteristics of price series and price changes (i.e. returns) are also presented in table 1.

[Table 1 is about here]

4. Empirical Procedures

The methodology adopted can be summarized as a two-stage procedure. In the first stage, the general two-step approach of Engle and Granger (1987) is used to verify the presence of long-run relationships. An asymmetric VAR-BEKK-GARCH model[1] is then followed to simultaneously investigate short-run price adjustments and volatility spillovers among markets.

The presence of cointegration is examined by first estimating three simple ordinary least squares (OLS) regressions to estimate the price relationships for three pairs of markets. Second, three unit root tests[2] for the regression residuals are conducted to confirm whether the price series are cointegrated. Because hog crisis in 1998 led to a big decrease in hog price (Figure 1), we incorporate dummy variables to catch the outliers. The potential long-run relationships for each pair of markets are written as follows:

$$\begin{aligned} {p_t}^{retail} &= \alpha_1 + \beta_1 {p_t}^{farm} + \delta_1 \mathrm{D} \\ {p_t}^{retail} &= \alpha_2 + \beta_2 {p_t}^{wholesale} + \delta_2 \mathrm{D} \qquad (1) \\ p^{wholesale} &= \alpha_3 + \beta_3 {p_t}^{farm} + \delta_3 \mathrm{D} \end{aligned}$$

where ${p_t}^j$ denotes the price level in logarithm in market j; α_i is a constant; β_i stands for the transmission elasticity since the price levels are in logarithm; and D is a dummy variable takes the value of one from October 1998 to December 1998 and zero otherwise.

Examination regarding the extent of price adjustments, price volatility, and volatility spillovers across markets is done in the second stage by employing a revised asymmetric VAR-BEKK-GARCH model (as shown in Eq. (2)). The upper specification indicates price adjustments in one market are affected by own lagged price adjustments, lagged price adjustments in the other

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[1] BEKK is named after Baba, Engle, Kraft and Kroner.

[2] Lag selections are based on BIC values

two markets, and a residual term. The volatility specification (i.e. the lower one) shows the conditional variance of the error process H_t is explained by the lagged error term ε_{t-1}, the lagged conditional variance/covariance H_{t-1}, and the asymmetric effect v_{t-1}.

$$\Delta P_t = \alpha + \Delta P_{t-p}\gamma_P^+ D_t{}^+ + \Delta P_{t-p}\gamma_P^- D_t{}^- + H_t^{1/2}\mu_t \qquad (2)$$

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'v_{t-1}v'_{t-1}D$$

$$\mathrm{H_t} = \begin{bmatrix} \mathrm{h}_{11} & \mathrm{h}_{12} & \mathrm{h}_{13} \\ \mathrm{h}_{21} & \mathrm{h}_{22} & \mathrm{h}_{23} \\ \mathrm{h}_{31} & \mathrm{h}_{32} & \mathrm{h}_{33} \end{bmatrix} \quad \mathrm{C} = \begin{bmatrix} \mathrm{c}_{11} & 0 & 0 \\ \mathrm{c}_{21} & \mathrm{c}_{22} & 0 \\ \mathrm{c}_{31} & \mathrm{c}_{32} & \mathrm{c}_{33} \end{bmatrix} \qquad (3)$$

$$\mathrm{A} = \begin{bmatrix} \mathrm{a}_{11} & \mathrm{a}_{12} & \mathrm{a}_{13} \\ \mathrm{a}_{21} & \mathrm{a}_{22} & \mathrm{a}_{23} \\ \mathrm{a}_{31} & \mathrm{a}_{32} & \mathrm{a}_{33} \end{bmatrix} \quad \mathrm{B} = \begin{bmatrix} \mathrm{b}_{11} & \mathrm{b}_{12} & \mathrm{b}_{13} \\ \mathrm{b}_{21} & \mathrm{b}_{22} & \mathrm{b}_{23} \\ \mathrm{b}_{31} & \mathrm{b}_{32} & \mathrm{b}_{33} \end{bmatrix} \quad \mathrm{D} = \begin{bmatrix} \mathrm{d}_{11} & \mathrm{d}_{12} & \mathrm{d}_{13} \\ \mathrm{d}_{21} & \mathrm{d}_{22} & \mathrm{d}_{23} \\ \mathrm{d}_{31} & \mathrm{d}_{32} & \mathrm{d}_{33} \end{bmatrix}$$

In the asymmetric VAR specification, ΔP_t a is 3 × 1 price changes vector for three markets; α is a 3 × 1 constant vector; ΔP_{t-p} is a 3 × 3p lagged price changes matrix; γ_P^+ and γ_P^- are 3p × 1 coefficient vector; $D_t{}^+$ and $D_t{}^-$ are dummy variables with: $D_t{}^+ = 1$ if ΔP_{t-p} is positive and 0 otherwise; and $D_t{}^- = 1$ if ΔP_{t-p} is negative and 0 otherwise. In the volatility specification, $\mathrm{h_{ij}}$ is the conditional variance/covariance with the subscripts 1, 2, and 3 denoting retail, farm, and wholesale markets, respectively. C is a lower triangular 3×3 parameter matrix. A, B, and D are 3×3 parameter matrices. The term $\varepsilon_{t-1}\,\varepsilon'_{t-1}$ is the product of residuals from the asymmetric VAR model; while v_{t-1} is a three-variable vector with $v_{t-1} = \varepsilon_{t-1} \bullet I[\varepsilon_{t-1} > 0]$ for wholesale and farm markets and $v_{t-1} = \varepsilon_{t-1} \bullet I[\varepsilon_{t-1} < 0]$ for retail market, where $I[\,]$ is an indicator function and the operator • denotes the Hadamard product. In our study, we assume retail price is more responsive to price decrease while wholesale and farm markets are more responsive to price increases. This assumption is consistent with existing studies which find commodity market price volatilities (retail level) tend to be more responsive to positive price changes (e.g., Black, 1976), and agricultural commodity price volatility is more likely to respond more to price decrease (e.g., Ng and Pirrong, 1974). Eq. (4)-(6) separately list how shocks and volatilities are transmitted over time and across markets to help identify more clearly on how volatilities among markets interact. Table 2 presents the correspondence between the Greek letters in Eq. (4)-(6) and the components of matrices C, B, A, D in Eq. (3).

$$\begin{aligned}
h_{11,t} = {} & \gamma_1 \\
& + \alpha'_1\varepsilon^2_{1,t-1} + \alpha'_2\varepsilon^2_{2,t-1} + \alpha'_3\varepsilon^2_{3,t-1} + \alpha'_4\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha'_5\varepsilon_{1,t-1}\varepsilon_{3,t-1} + \alpha'_6\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\
& + \beta'_1 h_{11,t-1} + \beta'_2 h_{22,t-1} + \beta'_3 h_{33,t-1} + \beta'_4 h_{12,t-1} + \beta'_5 h_{13,t-1} + \beta'_6 h_{23,t-1} \\
& + \delta'_1\sigma^2_{1,t-1} + \delta'_2\sigma^2_{2,t-1} + \delta'_3\sigma^2_{3,t-1} + \delta'_4\sigma_{1,t-1}\sigma_{2,t-1} + \delta'_5\sigma_{1,t-1}\sigma_{3,t-1} + \delta'_6\sigma_{2,t-1}\sigma_{3,t-1}
\end{aligned} \tag{4}$$

$$\begin{aligned}
h_{22,t} = {} & \gamma_2 \\
& + \alpha''_1\varepsilon^2_{2,t-1} + \alpha''_2\varepsilon^2_{1,t-1} + \alpha''_3\varepsilon^2_{3,t-1} + \alpha''_4\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha''_5\varepsilon_{1,t-1}\varepsilon_{3,t-1} + \alpha''_6\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\
& + \beta''_1 h_{22,t-1} + \beta''_2 h_{11,t-1} + \beta''_3 h_{33,t-1} + \beta''_4 h_{12,t-1} + \beta''_5 h_{13,t-1} + \beta''_6 h_{23,t-1} \\
& + \delta''_1\sigma^2_{2,t-1} + \delta''_2\sigma^2_{1,t-1} + \delta''_3\sigma^2_{3,t-1} + \delta''_4\sigma_{1,t-1}\sigma_{2,t-1} + \delta''_5\sigma_{1,t-1}\sigma_{3,t-1} + \delta''_6\sigma_{2,t-1}\sigma_{3,t-1}
\end{aligned} \tag{5}$$

$$\begin{aligned}
h_{33,t} = {} & \gamma_3 \\
& + \alpha'''_1\varepsilon^2_{3,t-1} + \alpha'''_2\varepsilon^2_{1,t-1} + \alpha'''_3\varepsilon^2_{2,t-1} + \alpha'''_4\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha'''_5\varepsilon_{1,t-1}\varepsilon_{3,t-1} + \alpha'''_6\varepsilon_{2,t-1}\varepsilon_{3,t-1} \\
& + \beta'''_1 h_{33,t-1} + \beta'''_2 h_{11,t-1} + \beta'''_3 h_{22,t-1} + \beta'''_4 h_{12,t-1} + \beta''''_5 h_{13,t-1} + \beta'''_6 h_{23,t-1} \\
& + \delta'''_1\sigma^2_{3,t-1} + \delta'''_2\sigma^2_{1,t-1} + \delta'''_3\sigma^2_{2,t-1} + \delta'''_4\sigma_{1,t-1}\sigma_{2,t-1} + \delta'''_5\sigma_{1,t-1}\sigma_{3,t-1} + \delta'''_6\sigma_{2,t-1}\sigma_{3,t-1}
\end{aligned} \tag{6}$$

Given the interactions of the vertically linked markets, price volatility ($h_{ii,t}$) in each market would be affected by market conditions in all three markets. The change of price volatility in one market can then be attributed to own-volatility impacts and volatility spillovers. Own-volatility effects are measured by coefficients α_1, β_1, and δ_1 in each equation that describe how own market's lagged error term (market shocks), lagged conditional variance (persistence) and asymmetric market shocks (asymmetry) affect price volatility. In terms of volatility spillover, they are triggered by the market conditions in one market directly and by the joint conditions of each pair of markets indirectly. The spillover effects are measured by the rest of the coefficients listed in Table 2.

[Table 2 is about here]

Asymmetries in price transmissions, price volatilities, and volatility spillovers are detected by: 1) conducting Wald tests to check the equality of positive and negative cumulative effects (as shown in Eq. (7)); 2) checking the statistical significance of coefficient δ_1 in each equation for the detection of asymmetry in price volatility; and 3) examining the significance level of the coefficients δ_2 to δ_6 to determine the presence of asymmetric volatility spillovers.

$$\begin{aligned} H_0&: \sum \gamma_P^+ = \sum \gamma_P^- \\ H_1&: \sum \gamma_P^+ \neq \sum \gamma_P^- \end{aligned} \tag{7}$$

5. Empirical Results and Discussion

Corresponding to the two-stage procedure, two sets of results are reported in this section. First, estimation results for the long-run relationships of each pair of markets are listed to illustrate how prices are transmitted in the long run. Second, results of the asymmetric VAR-BEKK-GARCH model are presented to explain how prices adjust in the short run and the nature of price volatility and the associated spillovers.

Resorting to the two-step approach developed by Engle and Granger (1987), we estimate the long-run relationships and conduct a set of unit root tests (ADF test) for the regression residuals. The unit-root tests results suggest long-run price relationship is present in each pair of markets, and the estimation results are shown below:

$$p^{retail} = (3.832 + 0.092D) + 0.389\, p^{farm}$$

$$(0.043) \quad (0.046) \quad (0.009)$$

$$p^{retail} = (4.141 + 0.244D) + 0.353\, p^{wholesale}$$

$$(0.038) \quad (0.010) \quad (0.007)$$

$$p^{wholesale} = (0.741 + 0.403D) + 0.919\, p^{farm}$$

$$(0.046) \quad (0.095) \quad (0.009)$$

All coefficients are statistically significant at 1% significance level with standard errors shown in parentheses. Estimate results indicate in the long run, when farm price decreases by 1%, retail price decreases by 0.389%, while wholesale price makes significant adjustments with a price decrease of 0.919%. For the wholesale-retail pair, retail price changes by 0.346% in response to a 1% change in wholesale price. Because incomplete price pass-through along the supply chain is often considered as an indication of market inefficiency, the non-fully response of retail price to the upstream price changes suggests retailers might have market power over wholesalers and farmers. On the other hand, the high transmission elasticity for wholesale-farm pair implies wholesalers operate in a competitive manner in the long run.

The estimated parameters for the asymmetric VAR model among all three levels of markets are presented in Table 3. Lag selections are based on BIC values. All three price series respond to the lagged price adjustments in all three markets. Retail price is only responsive to negative price changes in its own market, but is more responsive to the positive price changes upstream. This implies retailers might be able to enjoy the enlarged margin by being less responsive to the negative shocks in upstream markets. In addition, the results from cumulative effects show retail price can increase even the prices in its own and other markets decreases in the past.

[Table 3 is about here]

For wholesale price, it responds to both positive and negative price changes at retail level, but only responds to positive changes in its own and farm markets. Further, the coefficients on cumulative effects imply wholesale price would decrease even if retail price in the past two months increases and increase only if farm price increase. Such results suggest wholesalers seem to be disadvantageous over retailers as they do not benefit from the retail price increases, but advantageous over farmers as they only respond to positive farm price changes.

In contrast to retail price case, farm price are more responsive to positive price changes in its own market and negative changes downstream. Further, the coefficients on cumulative effects indicate farm price would decrease when retail prices increase in the past, while it would increase when wholesale price decreases. Analogous to the wholesale situation, the former makes economic sense and suggests farmers might be in a disadvantageous situation with not benefiting from the price increase at the retail level. Although the latter is statistically significant, it is not economically significant as it suggests farmers might possess seller power. First, it is contradictory to the finding that wholesalers only respond to positive price changes at the farm level, implying wholesalers may have buyer power. Second, from the theoretical perspective, factors such as the increasing size of packing firms, extensive use of production contracts and the perishable nature of hogs would not allow farmers to have seller power over the wholesalers (see Wise and Trist, 2010). Although some studies (e.g., Wohlgenant, 2013) pointed out farmers would also gain from the abovementioned factors that benefit the wholesalers, it is impossible for them to have greater power than wholesalers since the U.S. farmers have less access to the outside markets.

To rigorously examine whether asymmetric short-run price adjustments exist, Wald tests are conducted with the results presented in the lower panel of Table 3. The results confirm the existence of asymmetric price adjustments in retail and farm markets. Particularly, retail price asymmetrically adjust to the price changes in all three markets, and farm price asymmetrically adjust to the changes in its own and wholesale markets. Again, asymmetric transmission from wholesale to farm market is not economically significant. The asymmetric adjustments in its own market might be attributable to the decreasing number of hog farms and increasing specialization of hog production. However, we did not find evidence showing the presence of asymmetry at wholesale level.

Combined with the results from long run price relationships, we found retailers have the potential to exhibit anti-competitive behaviors in both the short- and long-run. Previous studies suggested it might be the increased firm size that allows retailers to better negotiate with farmers and wholesalers to secure lower prices and to take advantage of labor efficiencies (e.g., March and Brester, 2004). Additionally, meat products at this level are less perishable and easily storable than those in previous stages. Although wholesalers also possess the same feature of firm size increases, our results suggest they operate competitively in the short and long terms. One possible explanation is large processing plants need to ensure a smooth and undisrupted flow of hogs to achieve cost economies. Thus, wholesalers' desires to continue purchasing hogs to achieve cost savings would overwhelm any incentives to exercise market power by restricting purchases (GAO, 2009).

Results for the estimation of the conditional variances are presented in Table 4. Retail price volatility is affected by its own lagged shocks (α_1' in Eq. (4)) and lagged conditional variance. The greater value of β_1' indicates fluctuations caused by past shocks would remain for a long time (i.e.

persistency). Farm price volatility also follows this pattern (i.e. past shocks persist for a long time), but it is affected by the new shocks at a larger extent and is less persistent in comparison to the retail case. Moreover, no evidence is found showing the existence of asymmetry in retail and farm price volatilities. However, the statistically δ_1''' in Eq. (6) suggests the presence of asymmetry in wholesale price volatility. Wholesale price instability would increase when there are positive innovations in its own market, and this instability also persists (as suggested by β_1'' in Eq. (6)).

[Table 4 is about here]

Coefficients relating to the spillover effects suggest there are bi-directional volatility spillovers in all three pairs of markets. In addition, the price volatility in downstream markets would be affected by upstream markets both directly (i.e., though news and/or volatility from a single markets) and indirectly (i.e., through news and/or volatility from a pair of markets). For retail market, price volatility is affected by the news and volatility from the wholesale market both directly (as suggested by α_3 and β_3 in Eq. (4)) and indirectly (as suggested by α_5 and β_5 in Eq. (4)). However, wholesale market can only be affected by news and volatility generated by retail market indirectly (as suggested by β_5'' and in Eq. (6)). For the pair of retail-farm markets, farm market can affect the retail price volatility indirectly though news and volatility (as suggested by α_4 and β_4 in Eq. (4)), while retail market can only affect the farm market through news indirectly (as suggested by δ_4' in Eq. (5)). The statistical significant δ_4' indicates farm price volatility would asymmetrically increase when shocks in farm and retail markets move in the same direction. In terms of the spillover effects between wholesale and farm markets, wholesale price volatility would be affected by the news and volatility generated by farm market directly (as suggested by δ_3''

in Eq. (6)) and indirectly (as suggested by α_3'', β_6'', and δ_6'' in Eq. (6)). The statistical significant δ_3'' suggests positive shocks in farm market would asymmetrically contribute to wholesale price volatility. On the other hand, farm price instability would only be affected indirectly through news in wholesale market (as suggested by α_3' and δ_5' in Eq. (5)). The coefficient on δ_5' further implies when news from retail and wholesale markets move in different directions (i.e., one price increases and the other decreases), farm price volatility would increase. Because both retail and wholesale are in the downstream, the different directions of price changes would confuse farmers on how would the downstream price changes, and then the extent of uncertainty would enlarge.

Post model estimation, the Ljung and Box (1978) test for autocorrelation and McLeod and Li (1983) test for conditional heteroscedasticity are conducted to ensure the adequacy of the model. The testing results (Table 4) show no violation of the classical regression assumptions (i.e., no autocorrelation and no conditional heteroscedasticity). Figure 2 presents the time plots of estimated price volatilities at three levels of markets. Among three price series, price volatility at the farm level is of the highest and that at the retail level is of the least. Not surprisingly, farm price volatility reached its highest during hog crisis due to the significant drop of farm price and nonresponses of downstream prices. Even though price volatilities are in different scales for different market levels, we find all three exhibit similar patterns over time, which might be attributed to the spillover effects.

[Figure 2 is about here]

6. Conclusions

This study investigates the price linkages in the U.S. pork supply chain using monthly price series for the farm, wholesale, and retail markets. Both price level transmissions and price volatility spillovers are examined. Specifically, long-run price relationships are estimated by cointegression regressions, while short-run price adjustments and volatility interactions are analyzed through an asymmetric VAR-BEKK-GARCH model.

The estimation results on price level links suggest each pair of markets is cointegrated in the long run. Particularly, we find retailers might be advantageous over wholesalers and farmers, while wholesalers are operating competitively in the long term. In the short term, asymmetric price adjustments are detected in retail and farm markets. For the presence of asymmetry in price volatility, we found wholesale price instability would asymmetrically increase if there are positive innovations in its own market. Significant bi-directional spillovers are shown in all three pairs of markets with evidence of asymmetric spillovers to wholesale and farm market. Particularly, we find positive shocks to wholesale market would increase farm price volatility directly, while joint positive shocks in farm and wholesale markets would indirectly contribute to farm price instability. The presence of bi-directional volatility spillovers between any two levels of markets has shown different levels of markets along the chain do interact with each other through new innovations and volatility. This implies market participants should always consider the fluctuations in other relevant markets to ensure the appropriateness of their production decisions and risk management practices. Similarly, policies and programs that are aimed to stabilize price at one level of markets also need to take the other markets' condition into consideration. Also, the direction of market shocks should be given enough attention as they do affect the extent of price volatilities.

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Tables

Table 1: Summary Statistics for Log Prices and Price Changes

	Log Price (P)			Price Changes(p)		
	P^F	P^W	P^R	p^F	p^W	p^R
Mean	4.956	5.299	5.892	-0.002	-0.002	0.000
Std. Dev	0.441	0.414	0.170	0.088	0.048	0.023
CV	11.238	12.800	34.659	-0.023	-0.042	0.000
Skewness	0.134	0.568	1.010	0.412	0.419	1.274
(Kurtosis	-0.806	-0.861	0.345	3.154	1.119	10.029
ADF test	-2.565	-1.998	-2.495	-16.942*	-18.917*	-15.914*
(Lags)	(2)	(1)	(1)	(1)	(0)	(0)
PP test(Lag=4)	-2.599	-1.909	-2.273	-19.353*	-18.783*	-15.749*
KPSS test(Lag=4)	8.945*	9.465*	7.410*	0.018	0.053	0.076
Size		540			539	

Asterisk (*) denotes levels of significance at 5 percent level.
the critical value for ADF and PP tests is -2.867, and the critical value for KPSS test is 0.463.

Table 2: “Greek letters” - Nonlinear Combinations of the Estimated BEKK Parameter

Equation $h_{11,t}$	Equation $h_{22,t}$	Equation $h_{33,t}$
$\gamma_1 = c_{11}^2 + c_{21}^2 + c_{31}^2$	$\gamma_1 = c_{22}^2 + c_{32}^2$	$\gamma_3 = c_{33}^2$
$\alpha_1' = a_{11}^2$	$\alpha_1'' = a_{22}^2$	$\alpha_1''' = a_{33}^2$
$\alpha_2' = a_{21}^2$	$\alpha_2'' = a_{12}^2$	$\alpha_2''' = a_{13}^2$
$a_3' = a_{31}^2$	$a_3'' = a_{32}^2$	$a_3''' = a_{23}^2$
$a_4' = 2a_{11}a_{21}$	$a_4'' = 2a_{12}a_{22}$	$a_4''' = 2a_{13}a_{23}$
$a_5' = 2a_{11}a_{31}$	$a_5'' = 2a_{12}a_{32}$	$a_5''' = 2a_{13}a_{33}$
$a_6' = 2a_{21}a_{31}$	$a_6'' = 2a_{22}a_{32}$	$a_6''' = 2a_{23}a_{33}$
$\beta_1' = b_{11}^2$	$\beta_1'' = b_{22}^2$	$\beta_1''' = b_{33}^2$
$\beta_2' = b_{21}^2$	$\beta_2'' = b_{12}^2$	$\beta_2''' = b_{13}^2$
$\beta_3' = b_{31}^2$	$\beta_3'' = b_{32}^2$	$\beta_3''' = b_{23}^2$
$\beta_4' = 2b_{11}b_{21}$	$\beta_4'' = 2b_{12}b_{22}$	$\beta_4''' = 2b_{13}b_{23}$
$\beta_5' = 2b_{11}b_{31}$	$\beta_5'' = 2b_{12}b_{32}$	$\beta_5''' = 2b_{13}b_{33}$
$\beta_6' = 2b_{21}b_{31}$	$\beta_6'' = 2b_{22}b_{32}$	$\beta_6'' = 2b_{23}b_{33}$
$\delta_1' = d_{11}^2$	$\delta_1'' = d_{22}^2$	$\delta_1''' = d_{33}^2$
$\delta_2' = d_{21}^2$	$\delta_2'' = d_{12}^2$	$\delta_2''' = d_{13}^2$
$\delta_3' = d_{31}^2$	$\delta_3'' = d_{32}^2$	$\delta_3''' = d_{23}^2$
$\delta_4' = 2d_{11}d_{21}$	$\delta_4'' = 2d_{12}d_{22}$	$\delta_4''' = 2d_{13}d_{23}$
$\delta_5' = 2d_{11}d_{31}$	$\delta_5'' = 2d_{12}d_{32}$	$\delta_5''' = 2d_{13}d_{33}$
$\delta_6' = 2d_{21}d_{31}$	$\delta_6'' = 2d_{22}d_{32}$	$\delta_6''' = 2d_{23}d_{33}$

Shaded area indicates the measurement of indirect volatility spillovers.

Table 3: Estimates for Linear VARs

	Retail ($\Delta P_{R,t}$)		Farm ($\Delta P_{F,t}$)		Wholesale ($\Delta P_{W,t}$)	
Var	Coeff.	Std. Err	Coeff.	Std. Err	Coeff.	Std. Err
$\Delta P^{+}_{R,t-1}$	0.010	0.032	-0.565***	0.161	-0.240***	0.092
$\Delta P^{+}_{R,t-2}$	0.051	0.052	-0.230***	0.101	-0.040	0.044
$\Delta P^{-}_{R,t-1}$	0.085	0.052	-0.163	0.212	0.085	0.104
$\Delta P^{-}_{R,t-2}$	0.131***	0.048	-0.980***	0.203	-0.210***	0.110
$\Delta P^{+}_{F,t-1}$	0.024*	0.014	0.053	0.048	0.034*	0.020
$\Delta P^{+}_{F,t-2}$	-0.032**	0.013	0.100*	0.057	0.066***	0.025
$\Delta P^{-}_{F,t-1}$	0.040**	0.016	0.119	0.127	0.073	0.059
$\Delta P^{-}_{F,t-2}$	-0.008	0.012	-0.287***	0.090	-0.003	0.046
$\Delta P^{+}_{W,t-1}$	0.158***	0.022	0.178*	0.100	0.107**	0.045
$\Delta P^{+}_{W,t-2}$	0.137***	0.027	-0.169***	0.082	-0.136***	0.014
$\Delta P^{-}_{W,t-1}$	0.127***	0.030	0.014	0.212	0.026	0.111
$\Delta P^{-}_{W,t-2}$	0.060***	0.021	0.583***	0.143	0.012	0.083
Cumulative effects						
$\Sigma\, \Delta P_{R,t-i}{}^{+}$	0.061	0.055	-0.795***	0.142	-0.279***	0.080
$\Sigma\, \Delta P_{R,t-i}{}^{-}$	0.215***	0.069	-0.844***	0.207	-0.125	0.132
$\Sigma\, \Delta P_{F,t-i}{}^{+}$	-0.009	0.020	0.153**	0.077	0.099***	0.028
$\Sigma\, \Delta P_{F,t-i}{}^{-}$	0.032*	0.019	-0.168	0.151	0.070	0.069
$\Sigma\, \Delta P_{W,t-i}{}^{+}$	0.294***	0.028	0.008	0.132	-0.029	0.034
$\Sigma\, \Delta P_{W,t-i}{}^{-}$	0.187***	0.037	0.597**	0.241	0.039	0.125
Wald Tests						
		t-stat		t-stat		t-stat
H_0: $\beta_{\Sigma\, \Delta P_{R,t-i}{}^{+}} = \beta_{\Sigma\, \Delta P_{Rt-i}{}^{-}}$		-1.694*		1.159		-0.849
H_0: $\beta_{\Sigma\, \Delta P_{F,t-i}{}^{+}} = \beta_{\Sigma\, \Delta P_{F,t-i}{}^{-}}$		-1.709*		1.811*		0.399
H_0: $\beta_{\Sigma\, \Delta P_{W,t-i}{}^{+}} = \beta_{\Sigma\, \Delta P_{W,t-i}{}^{-}}$		2.410**		-1.826*		-0.470

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent).
Z^{ij}_{t-1} denotes the portion of deviation from equilibrium at market i corrected by market j

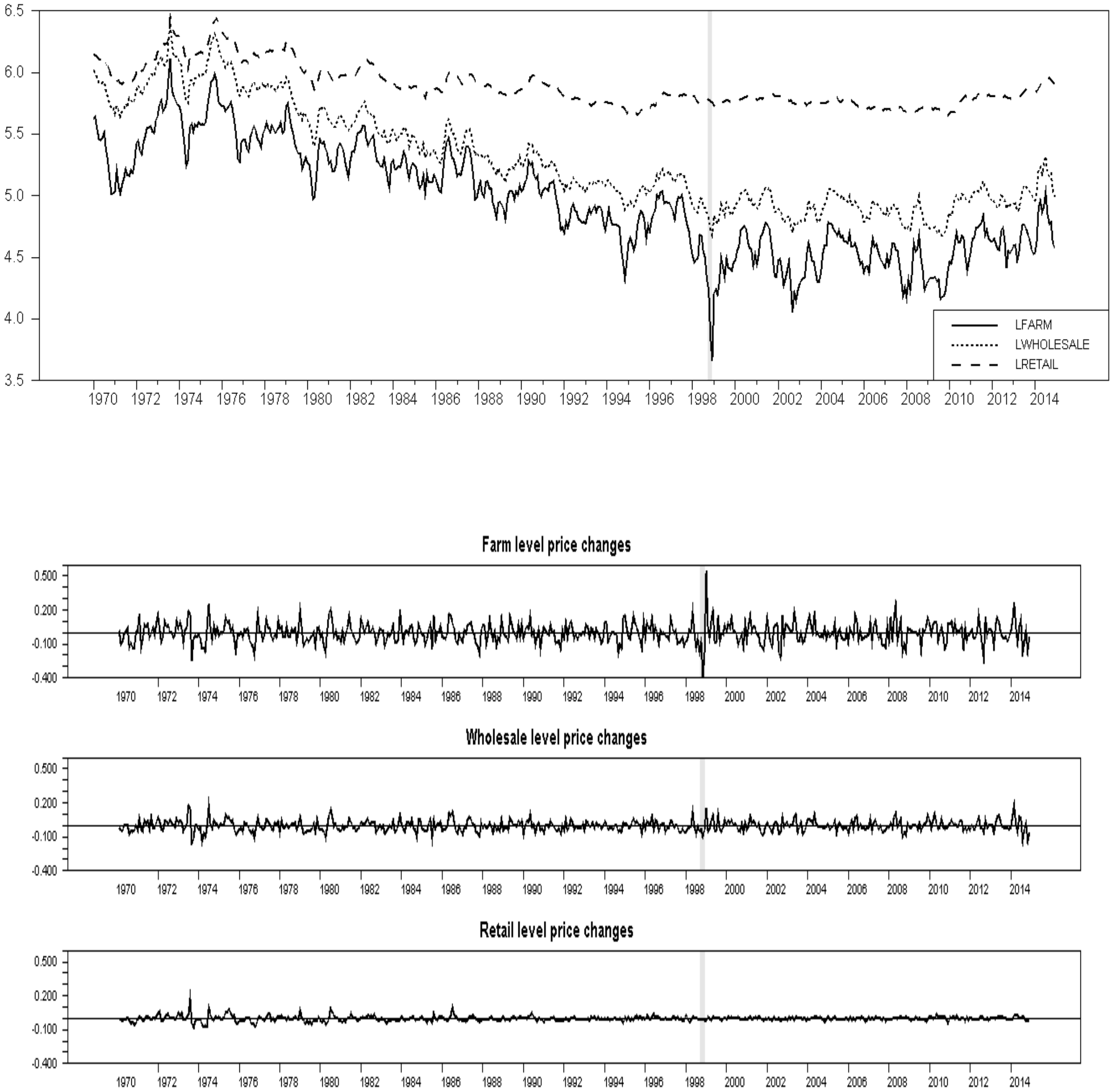
Table 4: Estimated Nonlinear Coefficients and Standard Errors from Asymmetric-BEKK Model among Three Levels of Markets Using Delta Method

	Equation $h_{11,t}$		Equation $h_{22,t}$		Equation $h_{33,t}$	
	Coefficient	St. Error	Coefficient	St. Error	Coefficient	St. Error
γ	0.002***	0.000	0.001*	0.000	3.27 E-009	1.04 E-006
α_1	0.075**	0.031	0.264***	0.088	0.016	0.015
α_2	0.001	0.001	0.000	0.005	0.003	0.011
α_3	0.021**	0.010	0.097	0.062	0.005	0.005
α_4	-0.018*	0.010	0.014	0.193	0.008	0.014
α_5	0.079***	0.027	-0.008	0.117	0.013	0.027
α_6	-0.009	0.007	-0.319**	0.144	-0.019**	0.008
β_1	0.818***	0.092	0.650***	0.158	0.202*	0.119
β_2	0.005	0.004	0.095	0.139	0.199	0.132
β_3	0.048**	0.020	0.024	0.059	0.021	0.018
β_4	0.133***	0.049	0.498	0.381	0131*	0.079
β_5	-0.397***	0.088	-0.096	0.167	0.401***	0.140
β_6	-0.032*	0.018	-0.252	0.332	0.132***	0.027
δ_1	0.081	0.060	0.064	0.052	0.332**	0.157
δ_2	0.000	0.000	0.861	0.649	0.001	0.010
δ_3	0.001	0.004	0.382	0.267	0.087***	0.030
δ_4	-0.005	0.009	-0.469**	0.221	0.014	0.125
δ_5	-0.016	0.036	1.146***	0.445	-0.027	0.248
δ_6						
δ_6	0.001	0.001	-0.312	0.222	-0.339***	0.122

Ljung-Box test	Q(4)=37.22,P-value=0.41
McLeod-Li test	Q(4)=117.99, P-value=0.94

Asterisks denote levels of significance (*for 10 percent, **for 5 percent, ***for 1 percent). Shaded area indicates the measurement of indirect volatility spillovers.

Figures



Note: The upper graph shows the monthly (logged) price, while the lower one shows the price changes. Shaded area is drawn to show the outliers.

Figure 1. Monthly Price and Price Changes for U.S. Pork at Farm, Wholesale and Retail Levels

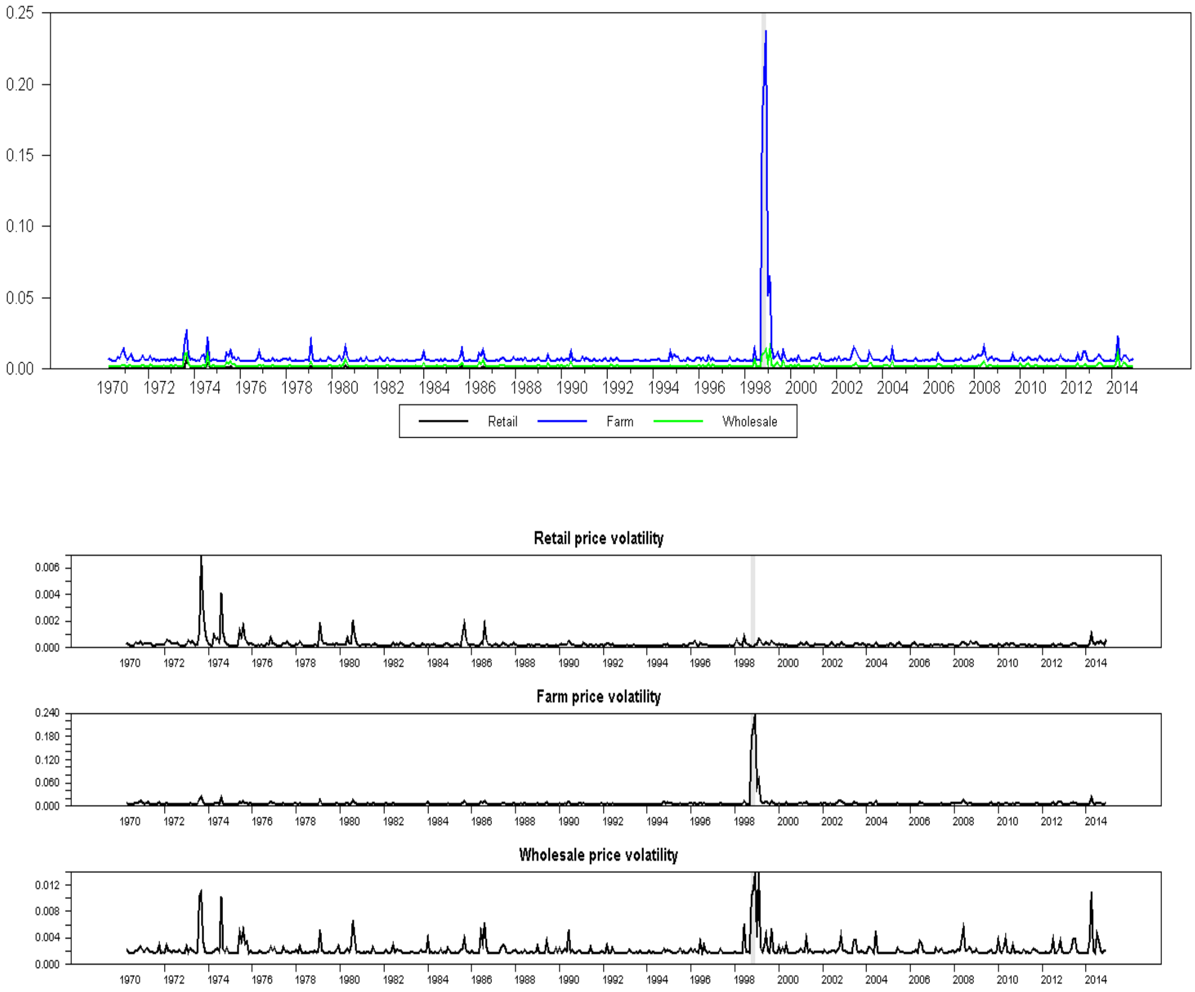


Figure 2. Conditional Volatility of Three Price Series