Dynamics of Price Volatility in the China-U.S. Hog Industries

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Abstract: This paper examines hog price linkages between the U.S. and China during the period June 1996 to December 2013. Volatility and spillover effects are modeled through a MGARCH-BEKK model. It is found that volatility in Chinese hog prices is explained by own-price volatility and past unexpected events (shocks); American hog price volatility, however, is mostly explained by its own past shocks (events in the U.S. market). One common aggregate linkage between the two markets is unidirectional volatility spillover effects from China to U.S. hog prices, paralleling the flow of hog-pork exports from the U.S. to China.

Keywords: hog and pork market, price volatility, volatility spillover, MGARCH-BEKK

Introduction

China, the European Union, and the U.S. are the main pork producers and consumers in the world. As the largest country of pork production and consumption, China produced 55.62 million metric tons (MMT) and consumed 56.10MMT of pork in 2013, which accounts for about half of the world's production and consumption. The U.S. is the third largest pork producer and consumer. In 2013, its annual pork output was 10.53 MMT and annual consumption 8.67 MMT, nearly 10% and 8% of global production and consumption. Both countries play important roles in global meat markets, and also trade with each other. While China's pork production has been expanding, production in the rest of the world has remained flat in recent years (USDA, 2014).

The 2013 purchase of U.S.' Smithfield Foods by China's Shuanghui International is but one example of the increasing role of China in the pork market. As the U.S. and China expand the pork trade, price linkages and volatility have important implications for farmers, business leaders and policymakers in both countries. Supply-side factors in China fluctuate over time which lead to price trends and fluctuations. Naturally, price volatility is of interest to both country swine industries. Sharp fluctuations often attract attention worldwide because of the revenue and risk implications for various market agents. Chinese hog prices have taken volatile swings while rising to a significantly high level since 2007 (Figure 1), which is the result of a complex mixture of factors, such as animal diseases, rising costs, governmental policies and so on. U.S. hog prices have been relatively stable during the whole period (Figure 1), however, external events can drive huge fluctuations. For instance, U.S. pork prices rose 10% after a virus killed millions of piglets in April, 2014(www. theguardian.com, 2014).

Pork trade between China and U.S. has expanded in recent years. Since 2007, Chinese pork imports surged due to the high domestic prices (Gale et al., 2012). In 2013, China imported 770, 000 metric tons (MT) of pork, which was nearly 15 times that of in 2006. As China's main trade partner, U.S. pork exports to China increased from about 57,000 MT in 2003 to more than 430,000 MT in 2012, about a fifth of all such exports (Philpott, 2013). The increase in Chinese pork imports points to the degree of increasing openness of the Chinese pork market.

As more and more pork is exported to China, it is expected that similar price relationships will be of more interest to market agents. Gale et al.(2012) found that the U.S. pork sales to China tended to rise and fall in rhythm with cyclical changes in China's hog prices. As a result, changes in pork trade flows lead to some price volatility in the U.S. News from the Chicago Board of Trade (CBOT, 2009) reported "China's pledge to lift a ban on U.S. pork drove U.S. December hog futures 2 percent in 2009."

Despite the increasing pork trade flows between China and the U.S., little empirical work exists on price relationships and volatility transmission between the two markets. Some studies have focused on the production, consumption and trade of China-U.S. swine industries (Pan et al. (2002), Fang et al. (2002), Liu et al. (2014)). However, only one paper analyzes the price transmission among China, U.S. and Europe (Tan, 2014). In fact, Tan focused on price levels rather than price volatility between China and U.S. hog markets, and the research on volatility transmission was not addressed.

The purpose of this paper is to study price volatility and the dynamic conditional correlation between Chinese and U.S. hog prices using monthly hog prices from 1996 to 2013. We address two aspects: firstly, the significance of dynamic conditional volatility in the respective markets; secondly, the volatility spillover effects for U.S. and Chinese hog producers. Historical hog prices are used to represent farm-level prices, and that will allow us to derive implications about volatility at the farm level.

The paper is organized as follows: first, we review the literature on price fluctuations and volatility transmission in Chinese and U.S. hog and pork markets. Then, we introduce the data and the economic models. An ECM-MGARCH-BEKK model is introduced to identify the price volatility in respective markets and the dynamic conditional correlation between two markets. Lastly, empirical results are interpreted and conclusions highlighted.

Literature Review

Price Volatility in the Chinese hog and pork Industry

Chinese scholars have observed the historical fluctuations and cycles in the swine industry (Lin et al., 1990; Xin et al., 1999). The sharp increase in pork prices since 2007 triggered a heated discussion on these issues once again. Numerous papers were published to study the price volatility in China's pork industry.

Some scholars tried to identify the characteristics of Chinese hog and pork prices using time series decomposition methods. Mao et al. (2008) use the Census X11 Seasonal Adjustment Method and H-P Filter Method to identify the seasonal, trend, cycle and irregular components in Chinese pork prices from 1995 to 2008. The results show that there are seasonal and cyclical variation in Chinese hog prices. The cycle length is about 35-45 month. Nie et al. (2009) used Census X12 Seasonal Adjustment Method and H-P Filter Method, Frequency Filter Method and found obvious and regular seasonality and cycles in pork prices, as well as unexpected events affecting pork prices significantly.

Price transmission in the Chinese hog and pork industry has been of considerable interest. Gao et al. (2012) analyzed the price relationship between pork and beans, corn, piglets and other factors of production by estimating a VAR model, impulse response functions and variance decomposition methods. Using the data from January 2000 to November 2010, they found a one-way causation between pork price and factors of production, and the direction is from pork to factors prices. By building an Error Correction Model, Ning et al. (2012) found a long-term equilibrium relationship and a short-term correction effect in Chinese hog industry chain with data of formula feed prices, hog prices and pork prices from 2001 to 2011. He et al.（2011）applied cointegration test, Granger causality test and impulse response function to analyze the relationship between corn prices and hog prices and found a long-run equilibrium relationship as well as a one-way price transmission between them.

Asymmetric price transmission has been reported in some studies. By using threshold ARCH model, Yang (2011) identified the asymmetric price transmission between Chinese hog and pork markets with the monthly wholesale prices data from 2000 to 2009, and found that pork wholesalers are more sensitive to the rising of pork prices and hog farmers are more sensitive to the declining of pork prices. Guo et al. (2011) analyzed the vertical transmission between hog price and pork price in Sichuan Province and Shanghai and found that here is a positive asymmetric price transmission.

Reasons for the sharp volatility in hog and pork prices have been of interest. Wu (2011) measured the price elasticity of pork supply with the data from 2004 to 2009, and found that the changes in supply were the main reason for price volatility. Xue et al. (2011) found three reasons for the price volatility: 1) the exit of small-scale farmers causing unbalanced supply structure; 2) the changes to large scale production leading to high cost; 3) the improper interference of government which has increased price fluctuation. Wang et al. (2012) thought that the external shocks, especially epidemic outbreaks, were the main reasons for price volatility, and the low degree of pig breeding organization exacerbated the fluctuation of pork prices. Li et al. (2012) confirmed that the domination of small-scaled feeders in China is the main reason led to the remarkable volatility of pork prices in recent years by comparing the size of production and volatility of pork price in China, the United States and Japan.

Besides, more and more scholars focused on price volatility in GARCH models. Yang (2011) analyzes dynamics of price volatility with monthly data of the hog wholesale price from 2000 to 2009 and found that there is a significant ARCH effect with lags of 1, 2 and 5. Similarly, Liu (2013) studies the relationship between the hog price volatility and hog price level in China among 1997-2012 by adopting descriptive statistics and ARCH model. The results show that hog price fluctuation is an important reason for high hog prices.

Price Volatility in the U.S. Pork Industry

Cycles and volatility in the U.S. hog and pork industry have been recurrently studied over the past century. The interest in cycles dates back to Haas and Ezekiel (1926), who studied the factors affecting U.S. hog prices.

The Cobweb Theorem has often been used as a basic theoretical framework for explaining recurring cycles in the hog and pork industry. Ezekiel (1938) introduced and applied the Cobweb Theorem to analyze the cyclical variation in the U.S. hog market. Under the framework, Harlow et al. (1960) measured supply response and supply-price elasticity to explain hog cycles. Later, the Cobweb Theorem was enriched by introducing adaptive expectations (Nerlove, 1958) and rational expectations (Muth, 1961). Producer's behavior was important to understand the Cobweb Theorem. Hayes et al. (1987) noticed the existence of countercyclical producers in hog industry and pointed out they could alter their production patterns sufficiently to eliminate hog cycles.

The characteristics of cyclical fluctuations in hog prices have changed over the years. Some decades ago, four-year cycles were measured in the U.S. pork industry (Harlow,1960). However, Spreen et al. (1982) found that the cycle length changed to 3.2 years based on the data from 1964 to 1980. Plain et al.（1981）identified the cycle length to be 2.75 years using weekly data from1970 to 1979. Shonkwiler et al.（1986）found that the typical 4-year cycle has changed to a 3-year cycle due to the technology progress in the pork industry.

Price transmission in the U.S. hog and pork industry has been studied since 1980s. Boyd (1988) tested the existence of price asymmetry within the U.S. pork marketing channel using an asymmetric pricing model and found that wholesale (packer) prices respond similarly to farm price decreases and increases. However, later research confirmed the asymmetric price transmission in the pork industry. Hahn at el. (1990) pointed out that retail prices of pork are more sensitive to price-increasing factors than to price-decreasing factors in the short run. Goodwin et al.(2000)evaluated price transmission among farm, wholesale, and retail pork markets using weekly price data for the period covering 1987 through 1998.An asymmetric, threshold error correction model was applied and the results showed that price transmission was unidirectional, flowing from the farm, to wholesale markets, to retail markets. Miller et al. (2001) used Engle's band spectrum regression to test the symmetry of high- and low-frequency cycles in weekly pork prices. The findings indicated that changes in wholesale prices are asymmetrically transmitted to retail prices in relatively low-frequency cycles. Jones (2005) analyzed the farm, wholesale and retail price relationships in the U.S. hog sector with a vector error correction model (VEC) and found that there is an imperfect price transmission between the market levels. Tests of Granger causality show that bidirectional causality existed in the hog and pork markets.

Chavas et al. (1991) analyzed the nonlinear dynamic processes in the pork cycle with a GARCH model and found that the pork cycle is apparently characterized by more complex dynamic forms. Holt et al. (2006) identified potential nonlinear features of the U.S. hog-corn cycle with the smooth transition autoregression (TV-STAR) models, using monthly data from 1910–2004. They found evidence of nonlinearity, regime-dependent behavior, and time-varying parameter change.

Price relationship between Chinese and American Pork industries

The study of price relationship between China and U.S. pork markets has been limited. Holst et al. (2011) analyzed the international synchronization of the pork cycle with the data for 113 countries (including China and the U.S.) from 1991 to 2008. No evidence confirmed the synchronisation of China and U.S. Pork Cycle. Osei-Agyeman et al. (2012) applied specific factors model to analyze the influence of U.S. pork trade with China on U.S. outputs and factor prices.

Hog price transmission between China-U.S. markets were studied by Tan (2014).With monthly data from 2000 to 2012, global price transmission was analyzed by using cointegration tests, VEC model and Granger Causality tests. The results showed that China is not influenced by European and U.S. markets and U.S. hog price responded mildly to the shocks from China.

Data and Methodology

Data

The data used in the paper are monthly hog prices covering the period from June 1996 to December 2013. Chinese hog prices are from Ministry of Agriculture of the People's Republic of China, which are the national average price of 480 selected Rural Market Faires (markets in rural areas). U.S. hogs prices are from the National Agricultural Statistical Service (NASS) of the U.S. Department of Agriculture, which are the Hog Farm Received Prices.

Considering the difference in unit of measurement, we convert unit of Chinese hog prices into U.S. dollars/lb. The monthly official currency exchange rates from the International Monetary Fund (IMF 2013) are used in the conversion.

Methodology

To address the price volatility and the dynamic conditional correlation in Chinese and U.S. hog markets, the method of causality in variance is selected. Causal relationships in systems of economic time series variables can be tested at two levels: Causality in mean and Causality in variance. One advantage of causality in variance is that it can capture the information flow from one market to another and provide an insight on the dynamics of economic prices (Granger et al. 1986). In empirical research, the multivariate generalized autoregressive conditional heteroscedasticity model (M-GARCH model) is a good choice to test for the causality in variance.

When agricultural price relationships are addressed, three aspects are usually considered (Kesavanet al., 1992): the long-run price relationships, the short-run dynamic behavior and the price volatility in certain period. The M-GARCH model captures the time-varying volatilities and co-movements between price series. Other model specifications are needed to identify the long-term relationships and short-term dynamic behavior. Following the research of Kesavanet al. (1992) who built a VEC-GARCH model to incorporate short-run dynamics, the steady-state relationship, and price volatility within a unified framework, we intend to apply the framework to analyze the price relationships between Chinese and U.S. hog markets.

Three steps are conducted to build the VEC-GARCH model. Firstly, a vector error correction model (VEC model) can be constructed when cointegration exists. So, cointegration test are adopted in advance to identify the long term relationships between China-U.S. hog prices. Secondly, a VEC model is built and parameters are estimated, which shows the information of long-term and short-term relationships between China-U.S. hog prices. Thirdly, Price volatility and dynamic conditional correlation are incorporated by using the MGARCH model.

Causality in Variance

Following the research of Granger et al. (1986), the causality in variance is defined in the following way. First, two time series PC_t and PA_t, as well as two information sets are defined by $IA_t = \{PA_{t-j}, j \geq 0\}andJ_t = \{PA_{t-j,}PC_{t-j}, j \geq 0\}$, where$PC_t$denotes Chinese hog prices and PA_tAmerican hog prices. IA_tmeans the information set of the U.S. hog market at time t, and $J_t$the information set of both markets(U.S. and China) at time t.

China prices Granger-cause U.S. prices in variance if equation (1) is true:

$$E\left[\left(PA_{t+1} - E(PA_{t+1}/J_t)\right)^2/IA_t\right] \neq E\left[\left(PA_{t+1} - E(PA_{t+1}/J_t)\right)^2/J_t\right] \qquad (1)$$

Equation (1)reflects the conditional volatility of the U.S. hog prices can be explained by the information of Chinese markets.

Similarly, the U.S. price Granger-causes China price in variance if equation(2) holds:

$$E\left[\left(PC_{t+1} - E(PC_{t+1}/J_t)\right)^2/IC_t\right] \neq E\left[\left(PC_{t+1} - E(PC_{t+1}/J_t)\right)^2/J_t\right] \quad , \qquad (2)$$

where, $IC_t = \{PC_{t-j}, j \geq 0\}$, denotesthe information set of the Chinese hog market at time t. Equation (2) means the conditional volatility of the Chinese hog prices are influenced by the information of U.S. hog markets.

MGARCH-BEKK Model

A bivariate GARCH model is chosen to study the price volatility and dynamic conditional correlation between Chinese and U.S. hog prices:

$$X_t = E(X_t/J_{t-1}) + \varepsilon_t, \qquad (3)$$

where $\mathrm{X_t}$ is a 2×1 vector of the Chinese and U.S. hog prices and $\mathrm{E(X_t/J_{t-1})}$ is a 2×1 vector of conditional means of the two prices given the *t-1* period information set. ε_t is a 2×1 vector of the error terms.

The vector ε_t can be modeled in several ways. One way is to model it as a bivariate BEKK representation (Engle and Kroner, 1995). One important feature of BEKK model is that it builds in sufficient generality allowing the conditional variances and covariance to influence each other. At the same time, it has few parameters and ensures positive definiteness of the conditional covariance matrix to satisfy the requirement to quadratic non-negative estimated conditional variance (Engle and Kroner, 1995).

The bivariate BEKK representation is as follows:

$$\varepsilon_t = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \sim N(0, H_t) \qquad (4)$$

$$H_t = B_0^{'} B_0 + A^{'} \varepsilon_{t-1} \varepsilon_{t-1}^{'} A + G^{'} H_{t-1} G \qquad (5)$$

$$H_t = \begin{pmatrix} \mathrm{h_{PC,t}} & \mathrm{h_{PC-PA,t}} \\ \mathrm{h_{PC-PA,t}} & \mathrm{h_{PA,t}} \end{pmatrix} \mathrm{B_0} = \begin{pmatrix} \mathrm{b_{11}} & \mathrm{b_{12}} \\ 0 & \mathrm{b_{22}} \end{pmatrix} \mathrm{A} = \begin{pmatrix} \mathrm{a_{11}} & \mathrm{a_{12}} \\ \mathrm{a_{21}} & \mathrm{a_{22}} \end{pmatrix} \mathrm{G} = \begin{pmatrix} \mathrm{g_{11}} & \mathrm{g_{12}} \\ \mathrm{g_{21}} & \mathrm{g_{22}} \end{pmatrix},$$

where $\mathrm{H_t}$ denotes the conditional variance-covariance matrix, with $\mathrm{h_{PC,t}}$ and $\mathrm{h_{PA,t}}$ conditional variances of the Chinese and U.S. hog prices, and $\mathrm{h_{PC-PA,t}}$ are conditional covariance for both markets. $\mathrm{B_0}$ is a upper triangular matrix of constants. A is a square matrix which shows how the conditional variances are correlated with the lagged squared errors. Matrix G shows how conditional variances are affected by the lagged conditional variances and covariance. In other words, the elements of matrix A measure the effects of past “shocks” or “news” on the current volatility, the elements in matrix G measure the degree of volatility persistence in the markets (Yonis, 2011).

To expand the expression, we get equations (6) and (7):

$$\mathrm{h_{PC,t}} = \mathrm{b_{11}^2} + \mathrm{a_{11}^2}\varepsilon_{1,t-1}^2 + 2\mathrm{a_{11}a_{21}}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \mathrm{a_{21}^2}\varepsilon_{2,t-1}^2 + \mathrm{g_{11}^2 h_{PC,t-1}} + 2\mathrm{g_{11}g_{21}h_{PC-PA,t-1}} + \mathrm{g_{21}^2 h_{PA,t-1}} \qquad (6)$$

$$\mathrm{h_{PA,t}} = \mathrm{b_{22}^2} + \mathrm{b_{12}^2} + \mathrm{a_{12}^2}\varepsilon_{1,t-1}^2 + 2\mathrm{a_{12}a_{22}}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \mathrm{a_{22}^2}\varepsilon_{2,t-1}^2 + \mathrm{g_{12}^2 h_{PC,t-1}} + 2\mathrm{g_{12}g_{22}h_{PC-PA,t-1}} + \mathrm{g_{22}^2 h_{PA,t-1}} \qquad (7)$$

Equations(6) and (7) provide a full description of the autoregressive conditional volatility influencing the price volatility in the Chinese and U.S. hog markets, respectively. In equation (6), the parameters $\mathrm{a_{11}^2}$ and $\mathrm{g_{11}^2}$ show the conditional variance of Chinese price is correlated with its own lagged squared error and own lagged conditional variance. Therefore, if $\mathrm{a_{11}^2} \neq 0$ and $\mathrm{g_{11}^2} \neq 0$, the volatility of Chinese hog prices will be influenced by its own past shock and volatility. Similarly, the parameters a_{22}^2 and g_{22}^2in equation(7) suggest that the price volatility of U.S. hog prices is affected by its own past shock and past volatility under the conditions that $a_{22}^2 \neq 0$ and $g_{22}^2 \neq 0$.

Volatility spillover is also measured in equations (6) and (7). In equation (6), the parameters a_{21}^2 and g_{21}^2 show the conditional variance of Chinese prices is correlated with the lagged squared error and lagged conditional variance of the U.S. prices. So, if $a_{21}^2 \neq 0$or $g_{21}^2 \neq 0$, Chinese price volatility is affected by the U.S. price volatility and the U.S. prices Granger-cause Chinese prices in variance. Similarly, the parameters a_{12}^2 and g_{12}^2 in equation (7) suggest that the U.S. price volatility is correlated with Chinese price volatility. If $a_{12}^2 \neq 0$ or $g_{12}^2 \neq 0$, Chinese prices Granger-cause the U.S. prices in variance.

Vector Error Correction Model

In order to estimate the parameters in the GARCH-BEKK model, we first model the mean price ($E(X_t/J_{t-1})$ in equation (3). As discussed above, a vector error correction model (VEC model) is expected to identify the long-run and short-run relationships between the means of the two price series.

A VEC model is a dynamic model in which the movement of the variables in any periods is related to the previous period's gap from long-run equilibrium. Engle and Granger (1987) introduced the model by using a direct link between cointegration and the error correction model (ECM) (Davidson et al., 1978), which provides an efficient means of partitioning the time-series data into two components: the long-run equilibrium characteristics and the short-run disequilibrium dynamics. Since then, the VEC model is widely used in econometric analysis.

The VEC model is represented as follows:

$$\begin{aligned} \Delta PC_t &= c_1 + \theta_1 ecm_{t-1} + \sum_{i=1}^{m} \delta_{1i} \Delta PC_{t-i} + \sum_{i=1}^{m} \gamma_{1i} \Delta PA_{t-i} + \varepsilon_{1t} \\ \Delta PA_t &= c_2 + \theta_2 ecm_{t-1} + \sum_{i=1}^{m} \delta_{2i} \Delta PC_{t-i} + \sum_{i=1}^{m} \gamma_{2i} \Delta PA_{t-i} + \varepsilon_{2t} \end{aligned} \quad (8)$$

where $\Delta PC_t = PC_t - PC_{t-1}$ and$\Delta PA_t = PA_t - PA_{t-1}$, are the first order differences of PC_t and PA_t, separately. The error correction term $ecm_{t-1} = PC_{t-1} - \mu - \beta PA_{t-1}$, is converted from the cointegration equation. When $ecm_{t-1} \neq 0$, it reflects a deviation of the price-series from steady-state relationship.

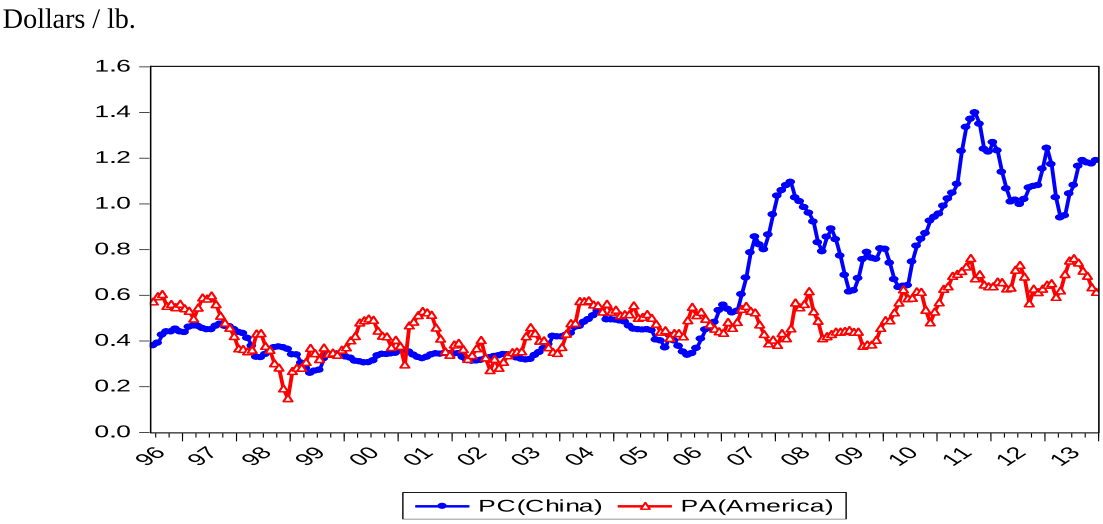
In equation (8), if the price-series deviate from steady-state relationship at period$t-1$, a correction mechanism brings the system back to equilibrium. The adjustment coefficientsθ_1 and θ_2 reflect the speed of the error-correction back to the long-term equilibrium. The short-term dynamics are embodied in the lagged terms of ΔPC_t and ΔPA_t, and the coefficients δ_{1i},δ_{2i},γ_{1i} andγ_{2i} reflect the influence of past price differences on current price differences.

Results

Descriptive Statistics

Monthly hog prices data of China and U.S. markets and their descriptivestatistics are shown in Figure 1 and Table 1.

Figure 1: Average Prices of China and U.S. hog markets from 1996 to 2013



Note: China price converted to U.S. dollars at official exchange rate. Prices are not adjust for inflation.
Source: China National Bureau of Statistics, and China Ministry of Agriculture, USDA

Table 1: Sample Statistics of PC and PA

Variable	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis
China hog prices(PC)	0.61	0.46	1.40	0.25	0.31	0.86	2.36
U.S. hog prices(PA)	0.48	0.48	0.76	0.15	0.12	0.14	2.60

Note: PC and PA are in USD/lb.

Figure 1clearly shows the increase in the price volatility in Chinese hog market since 2007. From 1996 to 2006, Chinese hog prices fluctuated within a relatively narrow range of $0.25 to $0.53 per pound. After a sharp increase during 2007, it reached a record high level ($1.09/ lb) in April, 2008. Then, prices declined to about$0.62/lb in April, 2009, and followed a period of lower prices through 2010. Later, Chinese hog prices rose to a new high and arrived at $1.40 per pound in November, 2011 and fell to the bottom ($0.93/lb) at April, 2013. The reasons for the high volatile prices in China are a series of complex factors, for example, the rising production costs, the outbreak of animal diseases, the resources constrains, and the intervene of public policy, etc. (Xue et al. (2011), Gale et al.(2012)). However, by contrast, U.S. hog prices have a relatively small fluctuation during the whole period with a range of $0.15 to $0.76 per pound. It also can be detected that Chinese hog prices have been significantly higher than U.S. hog prices since 2007.

Table 1 reports summary statistics for the prices series. During the period of study, hog prices in China (PC) have a greater mean price than those in the U.S. (PA), which means Chinese hog prices are generally higher than U.S. hog prices. Besides, both the difference between the maximum and minimum values and the values of standard deviation in PC are larger than that of in PA, indicating a higher level of fluctuation in China hog markets. The skewness value in PC is 0.86(much higher than 0.14 in PA), which means that higher than average (modal) Chinese hog prices occur more frequently.

Unit Root Test

The Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1981) and Phillips and Perron (PP)

(1988) unit root tests were implemented with each test of three models: models without intercepts or trend, models with intercepts, and models with intercepts and trends. The null hypotheses of the unit root tests are that unit roots exist. Both the initial prices series and their first-order differences are tested and the results are shown in table 2.It shows that the null hypothesis cannot be rejected for the initial price series, however, the first-order differences are stationary. That means both price series are integrated of I(1) and cointegration is an appropriate model for analyzing the relationship between China and U.S. hog prices.

Table2: Unit Root Test

		PC		PA	
		level	**1st difference**	**Level**	**1st difference**
ADF	Without intercept or trend	0.70	-9.58***	-0.50	-13.17***
	With intercept	-0.48	-9.63***	-2.43	-13.14***
	With intercept and trend	-2.45	-9.68***	-3.48	-13.14***
PP	Without intercept or trend	0.82	-6.84***	-0.54	-13.15***
	With intercept	-0.07	-6.72***	-2.57	-13.12***
	With intercept and trend	-1.78	-6.58***	-3.62**	-13.12***

Note: ***: denotes significant at 1% of significance, **: denotes significant at 5% of significance

Lag-length determination

The determination of the optimal lag length of the ECM is identified based on Akaike information (AIC), Schwartz Criterion (SC) and Hannan-Quinn (HQ) information criteria. Table 3 gives the results of Lag-length test with VAR model. It shows that lag length of 3 is best for our model.

Table 3: Lag length determination

LAG	AIC	SC	HQ
0	-1.597071	-1.564651	-1.583958
1	-7.238496	-7.141237	-7.199157
2	-7.608905	-7.446807	-7.543340
3	-7.738360*	-7.511422*	-7.646569*
4	-7.717269	-7.425493	-7.599252
5	-7.732796	-7.376181	-7.588554
6	-7.703510	-7.282055	-7.533041

Cointegration Test

Using the above lag length, we conducted cointegration test. Johansen System Cointegration Test (Johansen, 1990) was applied to identify whether there is a long-term relationship between China-U.S. hog prices. The results are shown in table 4. Both Trace and Max-eigenvalue tests indicate that there is one cointegrating equation at the 5% level. The results confirm the existence of a long term relationship between China and U.S. hog markets, and hog prices in two markets move together in the long run.

Table 4: Johansen cointegration test for PC and PA

r	Eigenvalue	Trace Statistic	λ_{max}
0	0.108	23.728**	23.626**
1	0.001	0.102	0.102

Notes: Given by Johansen and Juselius(1990), the 5% critical value for testing the null hypothesis of r=0 and r=1 are 15.495 and 3.841 in the trace test, and 14.265 and 3.841 in the maximum Eigenvalue test.
**: significant at 5% level

Estimation of VEC model for mean

The parameters in VEC model are estimated with lag length of 2 and the results are shown in equation (11) and table5.

$$ecm_{t-1} = PC_{t-1} - 0.9957 - \underset{(-6.8486)}{3.3189}PA_{t-1} \qquad (9)$$

Equation (9) shows the error correction term in VEC model. The figure in parentheses is the t-value. The equation reflects the presence of cointegration between PC_t and PA_t, which suggests a long term relationship between Chinese and American hog prices.

Table 5 shows the estimated coefficients in VEC model. The estimated coefficients θ_1 and $\theta_2$are statistically significant, which means there is a correction mechanism in the price series. Parametersδ_{11},$\delta_{12}$and$\gamma_{12}$are significant, which suggests that Chinese prices are affected by their own lag terms ΔPC_{t-1} andΔPC_{t-2}, as well as by the lag term of U.S. price differenceΔPA_{t-2}. Similarly, parameters $\delta_{21}$and$\delta_{22}$are significant, reflecting U.S. prices are affected by the lag term of Chinese price differences $\Delta PC_{t-1}$and ΔPC_{t-2}. The results show the interaction and the short-run dynamic adjustment process in Chinese and American hog markets.

Table 5: Estimation of VEC Model

Parameter	Estimated Coefficient	T-value
θ_1	-0.016793	-2.11223**
θ_2	0.043296	4.30497***
δ_{11}	0.735757	11.2333***
δ_{12}	0.145486	1.75594*
δ_{21}	-0.327175	-4.98849***
δ_{22}	-0.264568	-3.18892***
γ_{11}	0.009594	0.17864
γ_{12}	0.160446	2.36177***
γ_{21}	-0.018376	0.045749
γ_{22}	-0.33707	0.66339
R^2	0.4031	
F	27.284***	

Note: ***: significant at 1% level, **: significant at 5% level; *: significant at10% level

Estimation of GARCH-BEKK Model

Table 6 presents the estimated coefficients in MGARCH-BEKK model. Among all the estimated parameters, only four parameters (a_{11}, g_{11}, a_{22} and g_{12})are statistically significant. The residual Q-Statistics tests show that the result is effective in generally.

The estimated coefficients a_{11} and g_{11} are significant, which means the conditional variance of Chinese hog prices is affected by own lagged squared error and own lagged conditional variance. The estimated coefficients a_{21} and $g_{21}$are not significant, implying Chinese price volatility is not affected by U.S. price volatility. Besides, the result $|a_{11}| < |g_{11}|$, suggests that Chinese price volatility is much affected by past volatility rather than by past shocks, indicating a strong volatility persistence in Chinese hog market.

Table 6: Estimation of GARCH-BEKK Model

Parameter	Estimated Coefficient	P-value
b_{11}	0.0052	0.4855
b_{12}	-0.03323	0.4391
b_{22}	-0.00004	1.0000
a_{11}	-0.423218	0.0000
a_{12}	0.054720	0.7821
a_{21}	-0.052195	0.5214
a_{22}	0.412979	0.0021
g_{11}	0.857375	0.0000
g_{12}	0.427480	0.0046
g_{21}	0.212397	0.1904
g_{22}	0.160523	0.7226
Log-Likelihood Values	842.2004	
Q-Statistics: (lag=12)		
$\varepsilon_{1t}/h_{pc,t}^{1/2}$	17.743	0.124
$\varepsilon_{1t}^{2}/h_{pc,t}$	14.320	0.281
$\varepsilon_{2t}/h_{pa,t}^{1/2}$	20.304	0.062
$\varepsilon_{2t}^{2}/h_{pa,t}$	11.949	0.450

Notes: the Q-statistics denote Ljung- Box tests for up to 12th order serial correlation in the residual data in the model.

The estimated coefficient a_{22} is significant, which shows the conditional variance of the U.S. hog prices are affected by own lagged squared errors. The p-value of coefficient g_{22} is greater than 0.1, indicating the current conditional variance is not affected by lagged conditional variance. This means that the current price volatility is not dependent on past price volatility and the volatility persistence does not exist in the U.S. hog market.

Among the four parameters (a_{21} , a_{21}, $g_{12}$and g_{12}), which capture volatility spillovers across the markets, only $g_{12}$is statistically significant. This means that the conditional variance of the U.S. hog prices are dependent on the lagged conditional variance of Chinese hog prices. The U.S. price volatility is affected by the Chinese price volatility and Chinese prices Granger-cause U.S. prices in variance. The result shows evidence of unidirectional volatility linkages between Chinese and American hog markets and the direction is from China to America.

Conclusions and Discussion

Conclusions

China and the U.S. are two of the main pork producers and consumers in the world. The price relationships between the two markets are of interest as more U.S. pork is exported to China in recent years. Based on the research of Tan (2014), who analyzed price level transmission by VEC model and Granger Causality tests, this paper expands the research by focusing on the price volatility and dynamic conditional correlation between Chinese and U.S. hog industries. A MGARCH-BEKK model was used to capture the dynamic conditional volatility and possible spillover effects in the price series.

The conclusions are as follows: Firstly, the volatility of Chinese hog prices is mainly affected by own past volatility and past shocks. This result confirms that China is less influenced by other markets (Tan, 2014). China has a self-sufficient pork economy and the hog prices were affected by domestic supply and demand. China imported modest amounts of pork products comparing to its own output and consumption. The total imports in 2013 account for nearly 1.4% of national production in spite of the significant increase in Chinese pork imports since 2007.

Secondly, the volatility in American hog prices is affected by own past shocks as well as by Chinese price volatility. The unidirectional volatility spillover from Chinese to American hog prices indicates that the American hog market is influenced by the Chinese hog market. Considering the large size of Chinese pork production and consumption, it is not surprising that the price volatility will be transmitted to American hog markets as America is the largest pork exporter in the world.

Discussion

This paper finds alternative volatility transmission processes for Chinese and U.S. hog markets. The results presented above suggest a strong volatility persistence exists in Chinese hog market. However, the volatility persistence is not found in the U.S. hog market. That indicates that there is a price stabilization mechanism in the American hog industry. Further work should be done to explain how and why the volatility transmission processes are different in Chinese and U.S. hog and pork industries. Considering the sharp fluctuation in Chinese hog prices since 2007, it is urgent for China to study and establish an effective price stabilization mechanism in swine industry to benefit hog producers, consumers and other relevant agents.

This study also finds that China's price volatility in the hog market leads to price volatility in U.S. hog market. As the fourth largest pork importer in the world, China begins to play an important role in the world's pork markets and exerts influence on global pork prices. In recent years, the share of China pork imports in global total imports increased from nearly 2% in 2006 to over 10% in 2013.It is expected that China will import more pork in the near future because of the increasing domestic demand and high production cost (Gale et al., 2012).According to the USDA projections, U.S. pork exports will rise by another 0.9 metric tons by 2022, about a 33 percent jump from 2012 levels (Philpott, 2013).It is also expected that U.S. will export more pork to China and the pork trade linkage between the two countries will be stronger.

The results found in this paper appear consistent with current trends in these markets. As mentioned earlier, Shuanghui International surprised the hog-pork industry by purchasing Virginia-based Smithfield Foods, a transaction worth several billion dollars that was overwhelmingly approved by Smithfield Foods shareholders. In fact, it is reported that this was the largest purchase of a U.S. firm by a Chinese company (Slane, 2013). Both companies are large players in the hog-pork market in their respective countries. Thus, it is natural to expect that when market fundamentals change in China, either prices and/or volatility and spillover effects will impact prices in both countries. The results of this study indicate that volatility spillover effects are driven by the Chinese market and into the U.S. market. Should China's pork supply significantly shift upwards, the short-term impact would be reflected in more volatile hog prices in the U.S., if China continues to expand U.S. pork imports. If production from commercial operations in China increases, market trends and events that contribute to increased volatility in the Chinese market may lead to increased volatility spillover effects in U.S. hog prices. Based on recent financial news on Smithfield Foods, Smithfield kiosks in china have contributed to a synergistic effect of the merger and to increased pork sales and customer traffic (Wall Street Journal, 2014), and Smithfield plans to keep expanding in China. Currently, the flow of pork exports is from the U.S. to China. Should pork exports become bidirectional, volatility and spillover effects must require re-assessment.

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