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Asymmetric price transmission effect of corn on hog: evidence from China

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Abstract: In this study, we used monthly corn price and hog price data from January 2000 to June 2015 to conduct an empirical analysis based on a smooth transition regression (STR) model. The analysis confirms and explains the asymmetric transmission mechanism and process of the smooth transformation of corn prices to hog prices and measures the mechanism conversion threshold. Using the smooth transformation mechanism and its threshold as its foundations, this study breaks up continuous smooth transfer price volatility transmission effects into completely linear, not completely linear, and nonlinear mechanism states. Based on these states, the influence of corn price on hog price fluctuation is attributed to cost-push inflation, risk stabilisation effects, and the coexistence of cost-push and risk-stabilisation effects from the perspective of adaptive expectations.

Keywords: asymmetric transmission effect, corn prices, hog prices, mechanism decomposition, STR model

The hog industry is an important component of China's animal husbandry sector. According to data from the National Bureau of Statistics of China, 735.1 million hogs were slaughtered in 2015, an increase of 2.7% over 2014. Pork production in 2015, which accounted for 64.90% of total meat output, was 54.87 million tons, a decrease of 3.3% compared to 2014[1]. Since China liberalised the purchase and sale of hogs in 1985, the price of hogs, which is determined by the market, has had been highly volatile. In recent years, the cyclical fluctuations of hog prices have been more obvious (Na and Jia 2013). Since 2000, China has experienced four major hog-price peaks (in September 2004, March 2008, September 2011 and August 2015) and six large troughs (in May 2006, May 2009, April 2010, April 2013, April 2014 and March 2015). Prior to 2008, hog prices fluctuated less wildly; however, their volatility has increased since 2008, with frequent extreme fluctuations (Lu and Yue 2015). Normal price fluctuations represent an important method of not only regulating the relationship between supply and demand but also allocating market resources effectively. The fluctuation of extraordinary prices can have a negative effect on the health, stability and sustainability of the hog industry (Tao et al. 2009). Therefore, reducing abnormal fluctuations in hog prices is essential to maintain the health of the industry. The hog industry chain comprises the fattening, slaughtering and processing of piglets. The prices of hog-industry transfers along the production chain are shown in Figure 1. Through the hog-breeding industry chain, the largest impact on hog prices is caused by changes in the cost of hog production (Lizhong et al. 2013). Among the various costs of hog production, the cost of fodder is greatest. Therefore, a small change in feed price causes a large change in the cost of hog production (Chen and Qi 2013), and long-term fluctuations in hog prices are primarily driven by the price of feed (Qingquan 2013). Corn and soybean meal are major ingredients in hog feed, accounting for 50–60% of the feed cost,

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[1]Data source: http://www.askci.com/news/chanye/2016/01/21/15140ai1v.shtml

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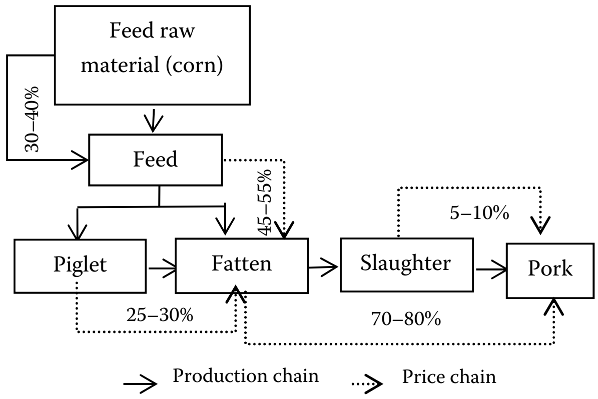

Figure 1. Delivery price in the hog industry chain

The percentages in the figure represent the proportion of the cost that connects to the next link. For example, 30–40% indicates that corn accounts for 30–40% of the cost of feed.

with corn alone accounting for 30–40% of the cost (Zihuan et al. 2015). Thus, the fluctuation of prices in the hog industry can be traced back to the inputs of raw feed and the fluctuation of corn prices. The fluctuation of corn prices will have an effect during feed processing, supplying piglets, fattening hogs and so on. Therefore, the following two issues were our main concerns in this study: (1) What are the features of price transmission of corn to hog? (2) What are the differences in the way that corn price fluctuations influence those of hog under different transmission mechanism? In addition, we have tried to explain the above problems from the perspective of producer expectations. We hope that our results could contribute to new interpretations and perspectives of the influence of corn price on hog price fluctuations.

LITERATURE REVIEW

Harlow (1960) first applied cobweb theory to analyse hog prices, hog production and the relationship between pig production and the numbers of pigs slaughtered and processed. He concluded that hog price fluctuation has a cycle of approximately four years. Subsequently, cobweb theory became an important theoretical method for the study of the fluctuation cycle of hog prices. In the 1950s, Harlow (1960) used cobweb theory to study hog price fluctuation in the United States. During this period, the lag effect of the supply response was considered in cobweb theory. Harlow noted that the length of the hog price fluctuation cycle was determined by producers' response to the expectation of hog prices when external factors are stable. Talpaz (1974) integrated cobweb theory with a distributed lag model to yield a multifrequency cobweb model. He identified fluctuation cycles of six different lengths in the sample period based on monthly data of piglets and hog grain ratios from 1964 to 1971 in the United States. Since the 1970s, scholars have been more inclined to study the application of econometric methods. Griffith (1977) examined monthly data of pork production, the number of hogs slaughtered and hog prices in Australia from 1958 to 1975. He studied the relationship between variable sequences using cross-spectral methods and concluded that price series have four-year fluctuation cycles. Chavas and Holt (1991) used the classical linear auto-regressive (AR) model to study the cycle of American hog prices. They found that the dynamic fluctuations of the hog cycle may be nonlinear and asymmetric. Nelson (1991) proposed an exponential generalised autoregressive conditional heteroscedasticity (EGARCH) model that includes a standardised disturbance term to distinguish the effects of positive and negative impact on price fluctuations. Based on generalised autoregressive conditional heteroscedasticity (GARCH) models, Glosten et al. (1993) and others introduced dummy variables and applied threshold methods to analyse the asymmetry of price volatility. The threshold model is widely used to study the asymmetric transmission of agricultural product prices. Goodwin and Harper (2000) researched American hog prices, wholesale prices and retail prices from 1998 to 1987. Their results showed that price transmission in the hog industry chain has both an obvious threshold effect and significant asymmetry. Abdulai (2002) used a threshold vector error correction (TVEC) model to study price transmission in the Swiss hog industry chain. The results showed that the speed of price transmission is faster when the difference between production and retail price is smaller. Holt and Craig (2006) provided evidence for the nonlinear characteristics of hog price fluctuation, system-dependent behaviour and structural changes. The results were based on hog-grain ratios over a period of nearly 100 years in the United States. McCullough et al. (2012) and others detected nonlinear characteristics in the hog cycle in America. Berg and Huffaker (2015) used diagnostic modelling methods to study hog price series over a ten-year period in Germany. They found that the nonlinearity of Germany's hog market was caused by time delay.

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Xian and Xiangyong (1999) was a relatively early Chinese scholar of hog price fluctuations whose work has been influential in China. He has shown that long-term fluctuations in hog prices are caused by the expected prices of producers. Jie and Ying (2007) performed a qualitative analysis of hog price fluctuation cycles. They hypothesised that price fluctuations in the hog industry will be long-lasting under market economy conditions. In recent years, scholars have tended to research hog price fluctuations using quantitative analysis, yielding significant insights related to the length of hog cycles. For example, Mao and Zhang (2009) noted that the cycle of hog price fluctuations in China is approximately 35–45 months. In addition, external shocks have an impact on hog price fluctuations. Wang and Li (2010) showed that the average length of hog-price cycles in China is approximately 30 months. Jie et al. (2015) analysed the characteristics of hog-market price fluctuations using the HP wave filter method. This research showed that the volatility cycle of hog prices, pork prices and piglet prices was longer than 40 months. In addition to the hog cycle, price transfers in the hog industry have attracted a great deal of scholarly attention. For example, Chen (2012) studied hog-price transmission mechanisms among the prices of pork, hogs, piglets and corn. The results showed that corn prices have a significant long-term impact on pork, hog and piglet prices. Zhou and Chen (2014) noted a long-term equilibrium relationship between hog prices and corn prices. Specifically, changes in corn prices have a significant impact on changes in hog prices. Wei and He (2013) arrived at the same conclusion. These studies provide important evidence for price transmission between corn prices and hog prices. Yang and Xu (2011) showed asymmetries in the transmission of hog and pork prices in China. Li (2013) noted that prices in the entire hog and pork industry chain are not a stable time series. The volatility of prices is obviously periodic, surpassing their traditional relationship of linear influence upon one another. Pan and Li (2014) analysed the nonlinear rule of hog price fluctuations by constructing a Markov regime switching model. Their results showed that hog price fluctuations in China have three regimes – price declines, steady growth and rapid growth. In addition, there are different levels of volatility transition probabilities and duration in different regions. Therefore, it is necessary to study the transition effects between hog prices and corn prices using nonlinear models.

Most research on the transfer of hog prices in China have employed relatively simple methods, including applications of the vector autoregression (VAR) model (such as in Ma et al. 2007; He and Fang 2012; Zhang et al. 2014 and Cong and Xiahua 2015) and threshold models (such as in Hu and Wang 2010; Li et al. 2012b and Dong 2015). Although traditional threshold models can depict the asymmetric and nonlinear characteristics of the transformation of price variables in different mechanisms, the transformations have jump characteristics. In 1994, Teräsvirta noted that transformation among different mechanisms might be continuous instead of jumping for many economic time series. Therefore, we have taken advantage of previous studies and explored the asymmetric effects of corn price fluctuations on hog price fluctuations using smooth transition regression (STR) models. STR models can describe nonlinear characteristics more accurately than the TAR model (Mao and Zeng 2009).

METHODOLOGY AND DATA

Methodology

The STR model was first developed by Clive Granger and Timo Teräsvirta and is used to describe the process of transition from one mechanism to another. The model assumes that the transfer process is continuous and smooth. As a parametric model, the STR model's description of nonlinear relationships between two variables is more realistic than that obtained using the traditional linear regression model. The standard model form of the STR is the following:

$$y_t = x_t'\varphi + \left(x_t'\theta\right) G\left(\gamma, c, s_t\right) + \mu_t \quad t = 1, 2, \dots, T \quad (1)$$

where y_t is the dependent variable vector, x_t is the independent variable vector, and x_t' is the transpose vector of the independent variable vector, including the k order lag variables of the dependent variable and n other independent variables. The specific forms can be represented as follows: $x_t = (1, x_{1t}, x_{2t}, \dots, x_{pt})' = (1, y_{t-1}, y_{t-2}, \dots, y_{t-k}; z_{1t}, z_{2t}, \dots, z_{nt})'$, and $p = k + n$ where $\phi = (\phi_0, \phi_1, l\phi_p)$ is the parameter vector of the model's linear part; $\theta = (\theta_0, \theta_1, l\theta_p)$ is the parameter vector of the model's nonlinear part; $\{\mu_t\}$ is the error sequence, independent and identically distributed; $G(\gamma, c, s_t)$ are the transition functions, the value of which are in the range 0–1; and s_t is the transformed variable. With changing s_t, the transition function is a smooth

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transition from 0–1; γ represents transition speed and *c* is the position parameter when a transition occurs.

According to the different forms of the transfer function, Granger and Teräsvirta (1993) divided the STR model into logical function type (LSTR) and exponential function type (ESTR).

When the transfer function is in the form

$$G(\gamma, c_{st}) = [1 + \exp(-\gamma(s_t - c))]^{-1} \ \gamma > 0 \quad (2)$$

the STR model is called logical STR, an LSTR, or an LSTR1 model. In this type of model, the transfer function *G* is a monotonically increasing function of variable s_t. When $s_t \to +\infty$, $G \to 1$; when $s_t \to -\infty$, $G \to 0$; when $s_t \to c$, $G \to 0.5$. $\gamma > 0$ is a recognition of constraints, which is a reaction of the speed shift from 0 to 1. The higher the γ, the larger the change in regime switching when s_t is relative to small *c*. When γ is closer to infinity, the transition function *G* that changes from 0 to 1 in the $s_t = c$ is instantaneous, and parameter *c* is used to determine the time state of the mechanism transition.

When the transfer function is in the form

$$G(\gamma, c, s_t) = 1 - \exp[(-\gamma(s_t - c)]^2 \ \gamma > 0 \quad (3)$$

the STR model is called index type STR or ESTR. In this type of model, the parameter c is also the turning point of mechanism transition. In contrast to the LSTR model, the model transfer function in ESTR is an even function, and the transfer function value is symmetric about point *c*. This reflects the symmetric impact of the transition variable s_t on the target variables. When $s_t \to c$, the transfer function $G \to 0$, and contrary to $G \to 1$. When the transfer function value approaches 0, the model remains only partially linear, and the nonlinear part gradually disappears.

Granger and Teräsvirta (1993) proposed a non-monotonic transfer function of the form

$$G(\gamma, s_t, c) = \{1 + \exp[-\gamma(s_t - c_1)(s_t - c_2)]\}^{-1} \quad \gamma > 0, c_1 \le c_2 \quad (4)$$

Such models also belong to logical STR models but differ from the LSTR1 model because the transfer function value is symmetric about the point $(c_1 + c_2)/2$. When the transfer variable s_t is closer to positive or negative infinity, the transfer function *G* approaches 1; for $c_1 \le st \le c_2$ all of the transfer variables s_t, $\gamma \to \infty$, transfer function $G \to 0$, in addition to the other value transfer function $G \to 1$. Models of this type are called LSTR2 models.

STR models provide an effective method for studying the nonlinear characteristics of economic time series. These models have been widely used in the analysis of exchange rates, real estate, stocks, economic growth and in other fields of research. In recent years, the method has also been applied in the field of agricultural products, achieving significant results. Li et al. (2012a) and others studied the asymmetric effects of food prices on price levels using an STR model. Shi and Wang (2015) studied the nonlinear conduction effect between China's beef and mutton prices using an LSTR model. Hog prices are similar to the economic variables set forth above; all have continuous and volatile time series. Using this model, the nonlinear and asymmetric characteristics of volatility can be described.

Data

In this study, we used monthly hog price and corn price data from January 2000 to June 2015 in China. The data are from the China Animal Husbandry Economy Information Network. Hog prices and corn prices are denoted by cl and ym, respectively. The corresponding differential variables are dcl and dym. All of the measurement results were computed with Stata 12.0 and JMulTi 4 software.

From the test results in Table 1, we observe that the original price series are non-stationary series; stationary sequences come after the first-order difference price series. In other words, there are two price series for the first-order single whole series sequence, that is, I (1) series. To construct STR models, dcl is the response variable, and the explanatory variables are the lagged variables in dcl, dym and dym.

Table 1. Data stationarity test results

	Variable	Statistic	Critical value		*P*-value	Conclusion
			1%	10%		
Original sequence	cl	−1.220	−3.482	−2.574	0.6651	non-stationary
	ym	−0.481	−3.482	−2.574	0.8957	
First-order difference sequence	dcl	−7.929	−3.482	−2.574	0.0000	stable
	dym	−9.842	−3.482	−2.574	0.0000	

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MODEL CONSTRUCTION AND ANALYSIS OF RESULTS

Model construction

The lag order number of the linear part of the STR model can be determined using the method of VAR. Applying the AIC and SC criteria, the variables dcl and variable dym optimal lag order number are all 4; that is, the optimal lag order of variables in the linear part of the model are combinations of (dcl_{t-4}, dym_{t-4}). The nonlinear part of the model is realised by computing a Taylor expansion. Making transfer function *G* a third-order Taylor series expansion in γ = 0, the equation obtained is called the auxiliary equation. The auxiliary equation-specific expressions are

$$(\gamma, c, s_t) = \lambda_0 + \lambda_1 s_t + \lambda_2 s_t^2 + \lambda_3 s_t^3 + \omega(\gamma, c, s_t) \tag{5}$$

where $\omega(\gamma, c, s_t)$ is the remainder of the Taylor expansion.

$$y_t = x_t'\beta_o + (x_t^* s_t)'\beta_1 + (x_t^* s_t^2)'\beta + (x_t^* s_t^3)' + \mu_t^* \tag{6}$$

where $\mu_t^* = \mu_t + (x_t'\theta)\omega(\gamma, c, s_t)$, $\beta_i = \gamma\beta_i^*$, i = 1, 2, 3 and $\mathrm{var}(\mu_t^*) = \mathrm{var}(\mu_t) = \sigma^2$, $x_t^* = (x_{1t}, x_{2t}, \cdots x_{pt})$.

In the STR model, the detected order of the nonlinear part is H_{04}: $\beta_3 = 0$; H_{03}: $\beta_2 = 0 | \beta_3 = 0$; H_{02}: $\beta_1 = 0 | \beta_2 = \beta_3 = 0$. If the original hypothesis is rejected, H_{03}'s *P*-value is the minimum that emerges from the testing of the three hypotheses, and we will select the LSTR2 model or the ESTR model; otherwise, we will choose the LSTR1 model. According to the test standard above, we tested for nonlinearity and determined the form of the transfer function for the STR model. The test results are shown in Table 2.

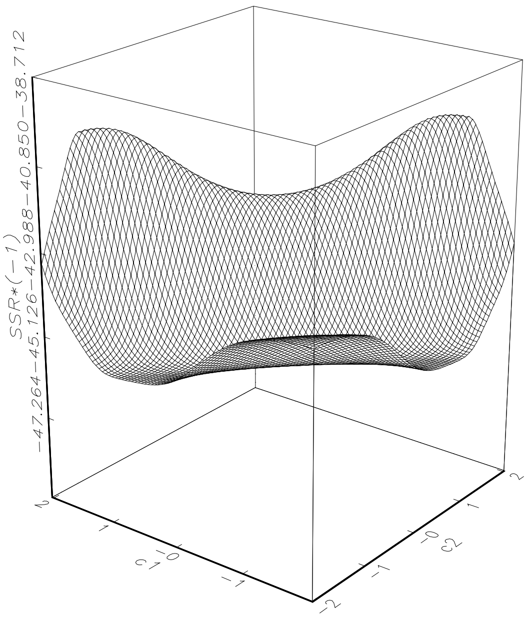

Figure 2. The search for a three-dimensional figure

The test results in Table 2 show that dcl_{t-2} should be the transformation variable; the form of the model is LSTR2. Next, we estimated the parameters of the model according to the choice of transfer variables and the form of the model.

RESULTS AND DISCUSSION

We used the two-dimensional grid search method to determine the initial value of the model. The range of the threshold parameter *c* is [−2.02, 2.01], and the range of the smoothing parameter γ is [0.50, 10.00], spaced within the range of 80 values. A total of 6400

Table 2. Test and transfer of nonlinear variable selection results

Variable	F	F4	F3	F2	Model form
dcl_{t-1}	0.0231	0.0621	0.7168	0.0116	LSTR1
dcl_{t-2^*}	0.0061	0.8371	0.0024	0.0259	LSTR2
dcl_{t-3}	0.0230	0.4532	0.0225	0.0709	LSTR2
dcl_{t-4}	0.0873	0.5732	0.5100	0.0076	Linear
dym_t	0.6641	0.8327	0.2374	0.6486	Linear
dym_{t-1}	0.2664	0.6202	0.3604	0.1062	Linear
dym_{t-2}	0.2531	0.0239	0.4676	0.9793	Linear
dym_{t-3}	0.2531	0.0543	0.2631	0.5801	Linear
dym_{t-4}	0.2531	0.3884	0.8363	0.0987	Linear
TREND	0.9643	0.6961	0.9374	0.8107	Linear

*for the transfer of the selected variables and the model form

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pairs of combinations were constructed. The residual sum of the squares for each combination of c and γ was calculated, and then the value of the two parameters was determined according to the minimum residual sum of squares. According to the calculation results, when SSR = 38.7120, the residual sum of squares is at a minimum; at this time, c and γ are initialised at $c_1 = -0.5916$, $c_2 = 1.2448$ and $\gamma = 5.4514$. Figure 2 shows the two-dimensional grid search results and the initial values of the parameters, that is, the lowest point in the map coordinates.

The model parameters were estimated based on the initial parameter values from Figure 2. Using the two-dimensional grid search method to determine the threshold parameters c_1 and c_2, we smoothened the initial value of transfer parameter γ into the LSTR2 model using the Newton-Raphson method to solve the conditional maximum likelihood function, and the estimated parameter values for the model were calculated. The model parameter estimation values are shown in Table 3.

In Table 3, some insignificant coefficient variables were not considered. Table 3 shows that the nonlinear part of the LSTR2 model is established, indicating an asymmetric influence of corn price fluctuations on hog prices. The critical values of the transfer function are $c_1 = -0.5960$ and $c_2 = 1.2186$, and the transfer function is approximately symmetric. Depending on the values of the transfer variables, this model features the following three mechanisms.

Mechanism one: This model features a linear transmission mechanism of corn price fluctuation to hog price fluctuation. Under these conditions, hog prices have little fluctuation. The model shows a completely linear state for the effect of corn price on hog price fluctuation.

In function 4, when the transfer variable is $\text{dcl}_{t-2} = 0.3113$ and the transfer function value is $G = 0$, this model shows only the linear part:

$$dcl_t = 0.5329\, dcl_{t-1} + 5.5773\, dym_t - 2.2066\, dym_{t-2} + 3.2708\, dym_{t-3} \quad (7)$$

At this point, the comprehensive influence of corn price on hog price fluctuation is 6.6415. The lag period of the combined effect is 3. When the corn price in the current period, the lagged 2 period and the lagged 3 period fluctuates by 1%, the lagged 3 period hog price fluctuates by 6.6415%. The influence of hog price fluctuation on the hog price itself is 0.5329, and its lag period is one. That is, in the current period, hog prices fluctuate 1%, which will cause the next period of hog prices to fluctuate by 0.5329%.

Mechanism two: The model features an incompletely linear conduction mechanism of corn price fluctuation on hog prices. Under these conditions, the fluctuation of hog prices expands, showing the incompletely linear state of the influence of corn price on hog price fluctuations.

In function 4, when the transition variables are $\text{dcl}_{t-2} = c_1$ or $\text{dcl}_{t-2} = c_2$, the transfer function value

Table 3. Results of model parameter estimation

	Variable	Initial value	Estimated value	Standard deviation	t-statistics	P-value
Linear part	dcl_{t-1}	0.5383	0.5329***	0.0890	5.9874	0.0000
	dym_t	5.6455	5.5773***	1.0393	5.3666	0.0000
	dym_{t-2}	−2.2181	−2.2066*	1.1743	−1.8791	0.0620
	dym_{t-3}	3.1006	3.2708***	1.1649	2.8078	0.0056
Nonlinear part	C	0.3004	0.3023**	0.1381	2.1897	0.0300
	dcl_{t-2}	0.3122	0.3140*	0.1861	1.6868	0.0936
	dcl_{t-3}	−0.4310	−0.4320***	0.1274	−3.3920	0.0009
	dym_{t-1}	−20.0999	−19.5814***	4.4227	−4.4275	0.0000
	dym_{t-2}	14.1645	13.2792**	5.1989	2.5542	0.0116
	dym_{t-3}	−17.0103	−15.7283***	5.3862	−2.9201	0.0040
	dym_{t-4}	11.7614	10.9137**	4.1985	2.5994	0.0102
	γ	5.6620	5.4514	3.4174		
	c_1	−0.5917	−0.5960	0.0389		
	c_2	1.2448	1.2186	0.0418		
	AIC	−1.3207	SSR	38.7120	SC	−9.8493

γ, c_1, c_2 for network search for the initial value, the t-statistic. Grid γ {0.50,10.00} grid c{−2.02,2.01}, *, **, *** indicate significance at the 1%, 5%, 10% levels, respectively

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is G = 0.5. Through pure linear to nonlinear state transformation, the model form is as follows:

$$dcl_t = 0.1512 + 0.5329dcl_{t-1} - 0.1570dcl_{t-2} - 0.2160dcl_{t-3} + 5.5773dym_t - 9.7907dym_{t-1} + 4.4330dym_{t-2} - 4.5934dym_{t-3} + 5.4569dym_{t-4} \quad (8)$$

Under these conditions, the comprehensive influence of corn price on hog price fluctuation is 1.0831. The lag period is four. When the corn prices in the current period, lagged 2 period, lagged 3 period and lagged 4 period fluctuate by 1%, the lagged 4 period hog price will fluctuate by 1.0831%. The influence of the hog price fluctuation on hog prices is 0.4739, and its lag period is three. When the corn prices in the current period, lagged 1 period and lagged 2 period fluctuate by 1%, the lagged 3 period hog price will fluctuate by 0.4749%.

Mechanism three: The model describes the nonlinear conduction mechanism of corn price fluctuation on hog price fluctuation. Under these conditions, the fluctuation of hog prices expands, showing the completely linear state of the influence of corn price on hog price fluctuation.

In function 4, when the transition variables $dcl_{t-2} < -0.5960$, namely, the hog prices in the second period of rising rates fall rapidly, the drop speed is more than 44.90% (exp(–0.5060) – 1)); when $dcl_{t-2} > 1.2186$, that is, hog prices in the second phase show rapid growth, the growth rate is more than 238.24% (exp(1.2186) – 1)). Under either of these conditions, the nonlinear characteristics of corn price fluctuations on hog price fluctuations will be fully affected. At this point, the model form is as follows:

$$dcl_t = 0.5329dcl_{t-1} + 5.5773dym_t - 2.2066dym_{t-2} + 3.2708dym_{t-3} + (0.3023 + 0.3140dcl_{t-2} - 0.4320dcl_{t-3} - 19.5814dym_{t-1} + 13.2792dym_{t-2} - 15.7283dym_{t-3} + 10.9137dym_{t-4}) \times G(\gamma(c, dcl_{t-2})) \quad (9)$$

where the transfer function is

$$G(\gamma, c, dcl_{t-2}) = \{1 + \exp[-5.4514(dcl_{t-2} + 0.5960)(dcl_{t-2} - 1.2186]\}^{-1} \quad (10)$$

At this point, the comprehensive influence of corn prices on hog price fluctuation is –4.4753. The lag period is four. When corn prices in the current period, lagged 2 period, and lagged 3 period fluctuate by 1%, hog prices in the lagged 4 period will fluctuate by –4.4753%. The influence of hog price fluctuation on hog prices is 0.4149, and its lag period is three. When corn prices in the current period, lagged 1 period and lagged 2 period fluctuate by 1%, hog prices in the lagged 3 period will fluctuate by 0.4149%.

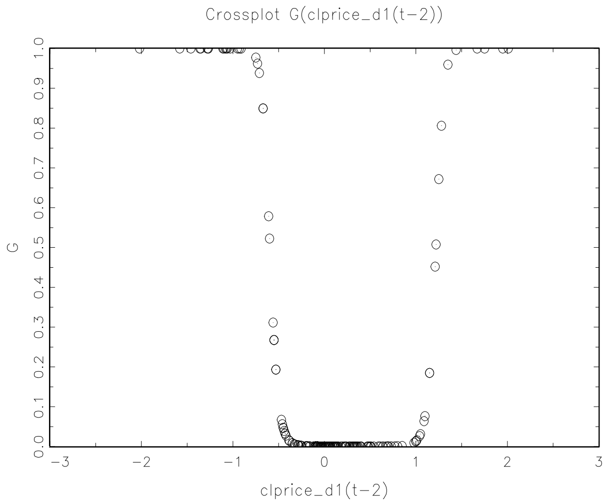

Figure 3. Transfer function diagram

Figure 3 shows the image transfer function of transfer variables dcl_{t-2}. The horizontal axis shows the transition variables dcl_{t-2}, and the vertical axis represents the transfer function G. As shown in the graph, the transformation function is symmetric about $dcl_{t-2} = 0.3113$, and when $dcl_{t-2} = 0.3113$, the value of the transfer function is $G = 0$. When $dcl_{t-2} < -0.5960$ or $dcl_{t-2} > 1.2186$, the transfer function value G approaches 1. The transfer function reveals the long-term effects of China's corn price and hog price fluctuations. Because of the different ranges of hog price fluctuations, this result shows the nonlinear characteristics of mechanism transformation.

Figure 4 shows the transfer function of the time series. The horizontal axis represents the time node, and the vertical axis represents the value of the trans-

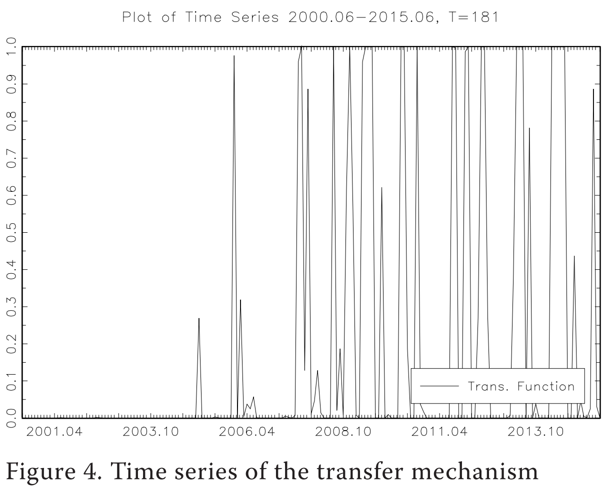

Figure 4. Time series of the transfer mechanism

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fer function. The figure shows the effect of China's corn price fluctuation on hog price fluctuation, which changes with time. The transfer function value is close to 1. This indicates that the model shows nonlinear characteristics. If the value is close to 0, the model shows linear features. As shown in Figure 3, the model shows linear characteristics for the influence of China's corn price fluctuation on its hog price fluctuation from June 2000 through November 2005 and August 2006 through June 2007. From November 2005 through July 2006 and from July 2007 through June 2015, the model shows nonlinear characteristics, particularly in July 2007, when the model frequently transfers between linear and nonlinear effects of corn price fluctuations on hog price fluctuations. The smoothing parameter $\gamma = 5.4514$ shows that the transfer speed is relatively fast.

ECONOMIC EXPLANATION

Economic theory holds that price is determined by supply and demand; a change in supply and demand will lead to price fluctuations. Pork meat, i.e., the downstream product of hogs, is primarily a consumption good, and thus its demand elasticity is relatively small. Its long production cycle demands that the supply of hogs is resilient (Wang 2015). According to the theory of adaptive expectations, hog-breeding farmers will make breeding decisions according to both historical and current prices so that they can influence supply in the hog market. Under the condition that demand is relatively inelastic, the fluctuation of hog prices is primarily related to the supply of hogs (Guo and Liu 2014).

When there is a small increase in hog prices ($dcl_{t-2} = 0.3113$), farmers expect the possibility of hog-price increases. To obtain more profit, farmers will increase farming inputs and delay slaughter. Simultaneously, market supply is reduced, and the price will increase further. Corn is the main raw material of pig feed, so breeding costs will increase if the price of corn increases, leading to a further increase in hog prices. Currently, the effect of corn price fluctuation on hog price fluctuation shows a positive effect. This is called the completely linear transmission mechanism state. We know that corn price plays the primary role in creating cost-push effects for hog prices.

As hog prices continue to rise ($dcl_{t-2} = 1.2448$), farmers expect the space of hog-price increases to gradually shrink, with the risk gradually increasing. Farmers begin to increase slaughter, and the market supply will increase, inhibiting hog price increases. Next, corn prices will rise, and the cost will increase; thus, the risk will also increase. Cost increases will exacerbate price fluctuations, and increased risks will limit price fluctuations; thus, corn-price increases have an expanded effect on hog prices. These risks increase and will offset the inhibition of hog prices. In the incompletely linear state, the positive effect of corn prices on hog prices is completely linear. Currently, the effect of corn prices on hog prices shows that the cost-push effect and the risk-stabilisation effect coexist.

When hog price fluctuations further expand ($dcl_{t-2} > 1.2186$), farmers expect that there will be no further increases in space and possibility. The likelihood of a decrease is greater that is, the risk is greater. If the price of corn increases again, costs and losses will increase when the price of hogs declines. To reduce both risk and losses, farmers will increase their slaughter, even in advance. This will rapidly increase the market supply, resulting in a sharp decrease in hog prices. At this time, both risk and cost will increase when the price of corn increases. Therefore, the effect of corn price fluctuation on hog price fluctuation changes from positive to negative. The effect of corn prices on hog prices is primarily manifested as a risk-stabilisation effect. The analysis of price declines is similar to that of price increases.

MODEL TEST

Unit root test

First, we conducted a unit root test of model residuals to determine the stationarity of the data residuals. In this study, the residual unit root test was performed using the augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. The test results are shown in Table 4.

From Table 4, we observe that the two test methods show that the residual sequence is at the 1% significance level for a smooth sequence, namely,

Table 4. Residual unit root test

Test method	Test statistics	Critical value below the 1% level	Conclusion
ADF	–5.9055	–2.5600	stable
KPSS	0.0378	0.7390	stable

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Table 5. No additional nonlinear test

Transition variable	F	F4	F3	F2
dcl_{t-1}	0.0052	0.2333	0.3341	0.0008
dcl_{t-2}	0.6549	0.7431	0.8842	0.1392
dcl_{t-3}	0.1031	0.5189	0.0144	0.5587
dcl_{t-4}	0.0550	0.6088	0.5811	0.0009
dym_t	0.1109	0.9429	0.0102	0.2490
dym_{t-1}	0.4368	0.4959	0.6107	0.2066
dym_{t-2}	0.0271	0.0132	0.3201	0.2706
dym_{t-3}	0.3629	0.6436	0.0903	0.6350
dym_{t-4}	0.2385	0.5215	0.7252	0.0347

the residual sequence is the unit root, and the model has good stability.

No additional nonlinear test

An additional nonlinear test for the model is needed to verify that the LSTR2 model can completely describe the nonlinear characteristics of the data. We tested the hypothesis with no additional nonlinear test and tested the alternative hypothesis with an additional nonlinear test. The test results are shown in Table 5.

Table 5 shows that whether the transfer variable is dcl_{t-1}, dcl_{t-2}, dcl_{t-3}, dcl_{t-4}, dym_t, dym_{t-1}, dym_{t-2}, dym_{t-3} or dym_{t-4}, all accept the hypothesis at the 10% significance level, namely, the LSTR2 model with no additional nonlinear test can describe the variable nonlinear characteristics.

Parameter stability test

To determine whether the model is reliable, we tested the stability of the parameters of the LSTR2 model. The test results are shown in Table 6, which shows that a model at the 10% significance level rejects the alternative hypothesis H_0; thus, the parameters of the LSTR2 model are stable, and the entire model is reliable.

The above test results show that the model residuals are stationary series and the model parameters are stable; that is, the model can describe the nonlinear relationship between the two variables. Thus, this can be considered an LSTR2 model estimation result with stability, reliability and a meaningful economic relationship.

Table 6. Model parameter stability test

Transfer function	*F*-value	df1	df2	*P*-value
H_1	0.9121	18	141	0.5651
H_2	1.0046	36	123	0.4737
H_3	1.1456	54	105	0.2738

CONCLUSION

This paper verifies the asymmetric effect of corn price fluctuations on hog price fluctuations by constructing an LSTR2 model based on hog prices and corn prices from January 2000 through June 2015 in China. In addition, we obtain threshold parameters and performance characteristics of the effect of corn price fluctuations on hog price fluctuations. Through an analysis of the model, we arrive at the following conclusions.

Conclusion one: The effect of corn prices on hog prices has nonlinear and asymmetric characteristics. This asymmetry is reflected in three aspects – strength of influence, lag period of impact and direction of impact.

Conclusion two: The effect of corn prices on hog prices manifests as a nonlinear transmission effect. Because of the different fluctuation ranges of hog prices, this effect has different mechanisms. Furthermore, the transition process is smooth rather than discontinuous, with jumps from one mechanism to another.

Conclusion three: Based on the analysis of the theory of adaptive expectations, we observe that the nonlinear conduction effect of corn prices on hog prices is caused by the different effects of corn prices in different mechanisms. Such effects, including the cost-push effect and the risk stabilisation effect, coexist.

Conclusion four: The self-adjustment conferred by hog price fluctuations indicates that for greater hog price fluctuations, the smaller the impact, the longer the lag period. In other words, the ability of hog prices to adjust themselves decreases as the amplitude of hog price fluctuations increases.

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