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Modeling the Pork Price Cycle in China Based on the Age Structure of Hogs

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Abstract. Pork price is essential in Chinese household consumption. Pork price prediction can advise the government to control the macroeconomy. Because of the explicitly periodic feature for pork price, previous researchers used fancy functions to fit the price cycle and predict it. However, only few researchers have tried to solve the pork price cycle based on the actual production of hogs. In this paper, a model is constructed using the most straightforward optimization and age structure of hogs to simulate the production process in pig farms and the pork price trend. The results match the claim that the price has a five-year cycle, and the model does well in empirical testing. Finally, some advice on controlling inflation is given based on the model prediction.

Keywords: Pork price, Hogs, Model, China

1. Introduction

Pork is the primary meat in the Chinese diet. Over 60% of the family's total meat consumption in China is pork [1]. It can significantly impact Chinese households' disposable income. When pork prices are too high, daily consumption of other products will reduce, slowing economic growth. Besides, pork price has been one of the critical components in the Consumer Price Index (CPI) that indicates the economy's inflation level. If the pork price can be predicted, the government can estimate the economic situation in the future and regulate the macro-economy to prevent an inflation outbreak or a recession [2].

Mordecai Ezekiel [3] introduced the cobweb theorem to the economic world. The theorem claims that if the commodity production is determined by the producers' response to the price, then the price of this commodity will show strong periodicity. Previous researchers found that pork is a specific agricultural product that follows the cobweb theorem [4]. Based on the theorem, the trend of pork prices is in a periodic pattern. It was confirmed that there is a 5- years pork price cycle in China [5]. Many researchers contributed a lot to studying this periodic cycle. Hovav Talpaz [6] used the cosine function to simulate the seasonal pork supply and demand change. The SETAR model and machine learning combination can also precisely fit the pork price in the Chinese market [7]. However, most researchers focused too much on the mathematic function, overlooking the phenomenon's economic meaning. Thus, this paper constructs the pork cycle

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model from the perspective of the actual production of hogs. It tries to simulate the pork price in China by modelling hogs' production process and age structure. Instead of using fancy functions to fit the price pattern, the model is constructed based on the interaction between pig farmers and pork prices, which is economically understandable.

2. Data and Data Preprocessing

2.1 Raw Data

Most data used in the model were collected from the Ministry of Agriculture and the Rural Affairs and National Bureau of Statistics, PRC, by Wind Financial Terminals. They are the weekly average pork price in 22 provinces in China, the monthly CPI of China, the number of sows and hogs supplied each month, the weekly average piglet price in 22 provinces in China, and the monthly forage price for pigs. These data are from 2006 to 2022.

In order to simplify, the model will take the average forage price, ￥2.74/kg, as the level of the forage cost. Using the same manipulation, the cost of each female piglet equals the average price of ￥37.4 per piglet.

The survival rates of the female pig are shown in Table 1, which are cited from the report [8]. All data in Table 1 are observed within two years and need an annualized operation in data preprocessing. The survival rates for hogs are displayed in Table 2, which are quoted from the research paper [9]. The data in Table 2 can be used directly to calculate the survival of newborn hogs. The birth information is collected in Table 3 from the paper [10].

Table 1. Survival rates used for female group

The number of parities	0	1	2	3~5	>6
Survival rate (%)	96.2	92.2	93.9	92.7	90.01

Table 2. Survival rates used for hogs' group

Stage	**Survival rate (%)**
weaned	82.4
alive after 20 weeks	97.3

Table 3. Birth information for piglets

Item	**Value**
Fertilized rate (per pig)	80%
Successful birth (per pig)	95%
Average piglets in a parity	10
The reserved female piglets per parity	0.16

Finally, it is commonly accepted that if the hog is weighed about 95.9 kilograms, it is mature and can go to the market. Most hogs will produce pork at 73% of their weight. Thus, the pork produced by each hog is about 70 kilograms.

2.2 Data Preprocessing

First, it is necessary to kick out the influence of inflation on pork prices. The adjusted pork price equals the pork price divided by the CPI value of its corresponding month.

Second, all data should be converted yearly to ensure the model reflects the actual relationships between each variable. The way to interchange the frequency is to take the average of all monthly data within the same year as the yearly data of that year.

As mentioned in the raw data part, the survival information for female pigs was observed within two years. It is convenient to gain the annual data if assuming that the annual survival rates remain the same in both years. Then, each 2-year survival rate s_{2-year} can be changed on an annual basis s_{1-year} based on the following formula (Eq. 1):

$$s_{1-year} = \left(s_{2-year}\right)^{\frac{1}{2}} \tag{1}$$

After calculation, the survival information for female pigs is in Table 4, in which all the data are converted into one year and can be used directly in the modelling.

Table 4. Annualized survival rates used for female group

The number of parities	0	1	2	3~5	>6
Survival rate (%)	98.08	96.02	96.9	96.28	94.87

3. Model Construction and Analysis

3.1 Model Construction

3.1.1 Basic Assumptions.

1.The model only considers the pig farmers' interaction with the market. External actions will not be considered (e.g., government regulations).

2.No swine epidemic happens.

3.There are 53 weeks in a year.

4.All female pigs get pregnant by artificial insemination. Pig farmers do not need to raise any male pigs.

5.Pig farmers make the production decision based on the same logic each year.

6.The birth rates and survival rates will not change.

3.1.2 Model Assumptions.

The model is divided into three parts: supply adjustment, production, and pork pricing (Fig. 1). At the beginning of each year, pig farmers will use the supply adjustment model to compute the adjusted number of female piglets. After that, they buy or sell the corresponding number of piglets and let the pigs reproduce. At the end of the year, all hogs go to the market, and the farmer earns money by selling pork at the current price. The supply-price mechanism in the pricing part decides the current pork price. These construct the whole production process in a year.

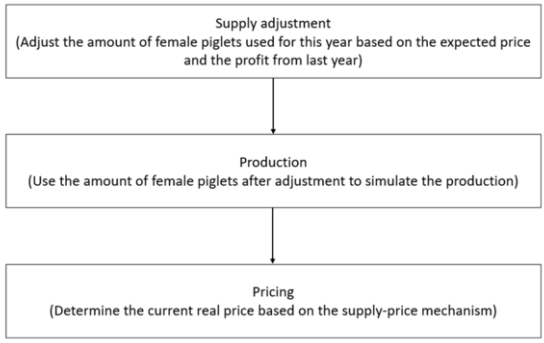

Fig. 1. The whole production process for each year

In order to learn about the whole process more clearly, the age structure in production will be discussed first in the following.

3.1.3 Age Structure in the Production.

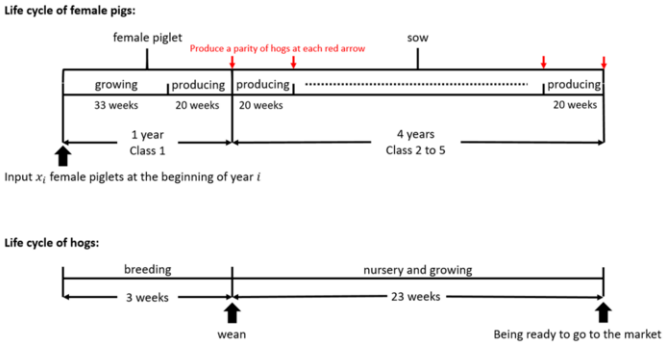

Fig. 2. The life cycle of female pigs and hogs

Hogs are pigs that will be slaughtered. Their meat will finally go to the market and be served as pork. In the life cycle of hogs, newborn hogs wean after three weeks. Then, they experience the nursery and growth stage in the next 23 weeks. After six months from birth, hogs mature and are ready to be sold. Besides, the total number of hogs produced each year is the sum of all hogs produced by each age class of female pigs. So, the model of hogs is correlated to the female pigs (Fig. 2).

Female piglets and sows are responsible for producing baby pigs. Female piglets have not or only given birth to one parity, while sows have produced more than one parity since their birth. Female pigs are responsible for producing baby pigs. Thirty-three weeks after birth, female baby piglets are sexually mature. Then, they start their first production. They will be fertilized in 1 week. After that, 80% of piglets will be pregnant successfully. About 15 weeks later, 95% of pregnant female piglets will successfully give birth to one parity. In the following four weeks, the female piglet nurses its babies. Each parity has ten baby pigs. Only 0.16 female babies are selected as the new female piglets. The other babies are chosen to be hogs. This is the whole process of production. It takes female piglets one year from birth to finish the first production. After their first production, these female piglets become sows. In the following years, sows will repeat the production again and again. Since each production takes only 20 weeks, it is assumed

that each sow can produce $\frac{53}{20}$ times a year. In each parity produced by sows, 0.08 newborn pigs with female sex are selected as female piglets (this number is 0.16 for newborn pigs of female piglets). Most pig farms will hold a sow for five years. After five years, the sows' fertility reduces, and they will be disposed of. Thus, assuming the number of age classes belonging to female pigs is five is suitable.

3.1.4 Supply adjustment.

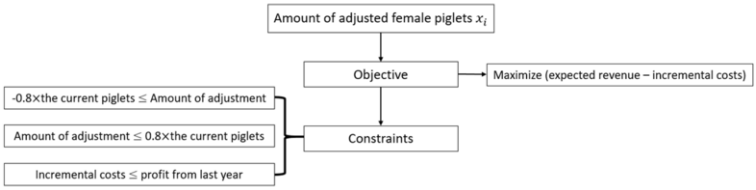

Fig. 3. The supply adjustment model

Total revenue = hogs supply after adjustment × the amount of pork per hog × expected price corresponding to the pork supply (2)

Incremental costs = incremental feed costs + purchase expenses (3)

Incremental feed costs = (survived amount of incremental female piglets + their babies) × 365 × forage consumed each day per pig × forage price (4)

Purchase expenses = price of female piglet × weight of a female piglet × adjusted amount of female piglet x_i (5)

Last year profit = total revenue of last year - total costs of last year (6)

Total revenue of last year = hogs supply last year × the amount of pork per hog × pork price last year (7)

Total cost last year = total feed costs last year + purchase expenses last year (8)

Total feed cost last year = (amount of female pig last year + amount of hog last year) × 365 × forage consumed each day per pig × forage price (9)

Purchase expenses last year = price of female piglet × weight of a female piglet × adjusted amount of female piglet last year x_{i-1} (10)

All components and their equations (Eq. 2, 3, 4, 5, 6, 7, 8, 9, 10) used in the model are shown above. In the supply adjustment part, pig farmers will adjust the production plan of hogs to maximize their profit in the following year based on the current expectation of pork price at the beginning of each year (Fig. 3).

Profit is the difference between revenue and cost. Revenue is the gain from selling pork produced by hogs this year. Cost includes the annual feed cost, purchasing expenses, and fixed costs. Feed cost is the total forage consumption of all pigs. Purchasing

expenses are the amount of money pig farmers spend buying new female piglets. Fixed cost is the amount of money used to expand pigsties and maintain the daily operation of pig farms. In the following model, the fixed cost is assumed to be 20.

In order to prevent pig farmers from increasing or decreasing the number of female piglets dramatically, some constraints are added. First, the inflow and the outflow of female piglets should be less or equal to 0.8 times the number of female piglets at the beginning of each year. Second, pig farmers invest their profits from last year to support the expansion of production. It means the incremental total cost due to the incremental female piglets should not exceed last year's profits. The incremental total cost includes two parts: feed cost and purchasing expenses. The incremental feed cost is the total amount of forage that new female piglets and their babies eat in one year.

A maximizing linear programming problem is built to obtain the adjustment of female piglets each year. This model will be conducted at the beginning of each year. It can indicate how many female piglets farmers should buy or sell that year.

3.1.5 Hog supply-pork price transmission mechanism.

Because the model does not emphasize the economic relationship between supply and price, creating a complex model simulating the detailed supply-price mechanism is unnecessary. It is enough to assume that the relationship between supply and price follows a linear function.

3.2 Mathematical modeling

3.2.1 Variables.

The variables are displayed in Table 5.

Table 5. Variables description

Variable	Meaning	Value
u_i	the total number of female pigs at year i	
h_i	the total number of hogs at year i	
$u_{i,j}$	the number of female pigs in the j^{th} age class at year i	
x_i	the number of newly-purchased female piglets at year i	
b_j	expected number of offspring from a female pig in age class j	b_1=7.6 $b_{2,3,4,5}$=20.14
$b_{f,j}$	expected number of female piglets produced by a female pig in age class j	$b_{f,1}$=0.16 $b_{f,2,3,4,5}$=0.212
$b_{h,j}$	expected number of hogs produced by a female pig in age class j	
$s_{w,n}$	fraction of hogs surviving from their birth to mature	0.801752
$s_{f,j}$	fraction of female pigs surviving from the $j-1^{th}$ class to the j^{th} class	$s_{f,1}$=0.974385 $s_{f,2,3,4,5}$=0.967479
p_i	the pork price at year i	
$\hat{p}_i$	the expected pork price at beginning of year i	
q_i	the amount of hog supply at year i	
f	the amount of forage a pig eats in one day	1.5
pf	the price of forage	2.71
r	the amount of pork a hog produces	70
c	the price of female piglets	37.4
w	the weight of a female piglet	30
$profit_i$	the profit earned in year i	

3.2.2 Model Formulations.

Supply adjustment model. (Eq. 11, 12, 13, 14)

$$\max_{x_i}\left(h_i + s_{w,n}b_{h,1} \times x_i\right) \times r \times \widehat{p_i} - \left[x_i \times \left(s_{w,n}b_{h,1} + s_{f,1}b_{f,1}\right) \times 365 \times f \times pf + c \times w \times x_i\right] \tag{11}$$

$$s.t. -0.8u_{i,1} \leq x_i \tag{12}$$

$$x_i \leq 0.8u_{i,1} \tag{13}$$

$$x_i \times \left(s_{w,n}b_{h,1} + s_{f,1}b_{f,1}\right) \times 365 \times f \times pf + c \times w \times x_i \leq profit_{i-1} \tag{14}$$

The price prediction formula at the beginning of each year is: (Eq. 15)

$$\hat{p}_i = n + m \times (h_i + s_{w,n}b_{h,1} \times x_i) \tag{15}$$

The profit part is calculated by: (Eq. 16)

$$profit_{i-1} = (0.8 \times h_{i-1} \times r \times p_{i-1}) - (h_{i-1} + u_{i-1}) \times f \times pf - x_{i-1} \times w \times c \tag{16}$$

Age structure of female pigs. (Eq. 17)

$$\begin{aligned} u_{i,1} &= s_{f,1}[b_{f,1}(u_{i-1,1} + x_{i-1}) + b_{f,2}u_{i-1,2} + \ldots + b_{f,5}u_{i-1,5}] \\ u_{i,2} &= s_{f,2}(u_{i-1,1} + x_{i-1}) \\ &\vdots \\ u_{i,5} &= s_{f,5}u_{i-1,4} \end{aligned} \tag{17}$$

The matrix form: (Eq. 18)

$$\begin{bmatrix} u_{i,1} \\ u_{i,2} \\ \cdots \\ u_{i,5} \end{bmatrix} = \begin{bmatrix} s_{f,1}b_{f,1} & s_{f,1}b_{f,2} & \cdots & s_{f,1}b_{f,4} & s_{f,1}b_{f,5} \\ s_{f,2} & 0 & \cdots & 0 & 0 \\ & & \cdots & & \\ 0 & 0 & \cdots & s_{f,5} & 0 \end{bmatrix} \left(\begin{bmatrix} u_{i-1,1} \\ u_{i-1,2} \\ \cdots \\ u_{i-1,5} \end{bmatrix} + \begin{bmatrix} x_{i-1} \\ 0 \\ \cdots \\ 0 \end{bmatrix} \right) \tag{18}$$

The number of female pigs: (Eq. 19, 20)

$$u_i = Lu_{i-1},\ L\ is\ the\ Leslie\ matrix \tag{19}$$

$$u_i = \sum_{j=1}^{5} u_{i,j} \tag{20}$$

The number of sows: (Eq. 21)

$$sow_i = \sum_{j=2}^{5} u_{i,j} \tag{21}$$

The number of female piglets: (Eq. 22)

$$female\ piglet_i = u_{i,1} \tag{22}$$

Supply of hogs.

The birth rate of hogs in the j^{th} group of female pigs ($b_{h,j}$) is calculated by: (Eq. 23, 24)

$$b_{h,j} = b_j - b_{f,j}\ ,\ j = 1,2,3,4,5 \tag{23}$$

$$h_i = s_{w,n}[(b_{h,1} \times u_{i-1,1} + b_{h,2} \times u_{i-1,2} + b_{h,3} \times u_{i-1,3} + b_{h,4} \times u_{i-1,4} + b_{h,5} \times u_{i-1,5}) + b_{h,1} \times x_{i-1}] \tag{24}$$

The matrix form is: (Eq. 25)

$$\begin{bmatrix} h_{i,1} \\ h_{i,2} \\ \cdots \\ h_{i,5} \end{bmatrix} = [s_{w,n}b_{h,1} \quad s_{w,n}b_{h,2} \quad \cdots \quad s_{w,n}b_{h,4} \quad s_{w,n}b_{h,5}] \left(\begin{bmatrix} u_{i-1,1} \\ u_{i-1,2} \\ \cdots \\ u_{i-1,5} \end{bmatrix} + \begin{bmatrix} x_{i-1} \\ 0 \\ \cdots \\ 0 \end{bmatrix} \right) \tag{25}$$

The annual hog's supply: (Eq. 26)

$$h_i = \sum_{j=1}^{5} h_{i,j} \tag{26}$$

Hog supply-pork price transmission mechanism. (Eq. 27)

$$p_i = n + m \times q_i \tag{27}$$

4. Results

4.1 General trend

After fitting in the value of each variable, the model simulates the pork price trend from 2007 to 2034. The result is shown in Fig. 4.

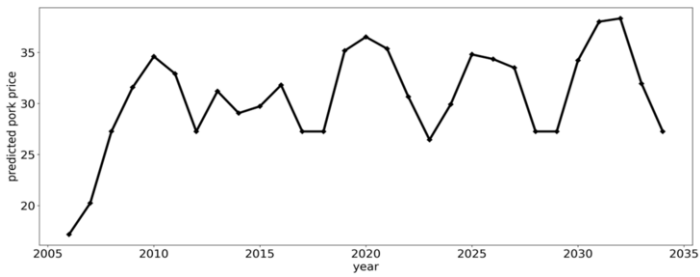

Fig. 4. Simulation until year 2034

The simulation demonstrates a 5-year periodic cycle, matching the finding in [5].

4.2 Empirical Testing

Combining the actual adjusted pork price and the predicted one from our model, we find that our model gives a proper fit (Fig. 5). The correlation between these two data sets is 0.58, which is significant.

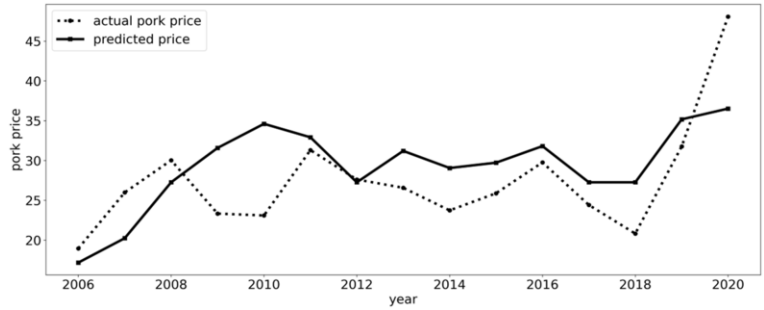

Fig. 5. The comparison between the historical data and the predicted value

The predicted price does not match the trend between 2008 and 2013. The correlation during this period is only -0.24. This phenomenon can be due to some improper assumptions at the beginning of the simulation. From 2006 to 2013, the model adjusts to find the proper age structure fitting the periodic cycle. Thus, the model matches the data well some years later while experiencing a bad fit in the first several years.

4.3 Sensitivity Analysis

The sensitivity analyses are conducted on two hyperparameters, the forage price and the price of female piglets.

4.3.1 Forage Price.

The forage price's mean and standard deviation are 2.74 and 0.45, respectively. The analysis simulates the pork price while assuming the forage price is mean plus or minus one standard deviation. The results are displayed in Fig. 6.

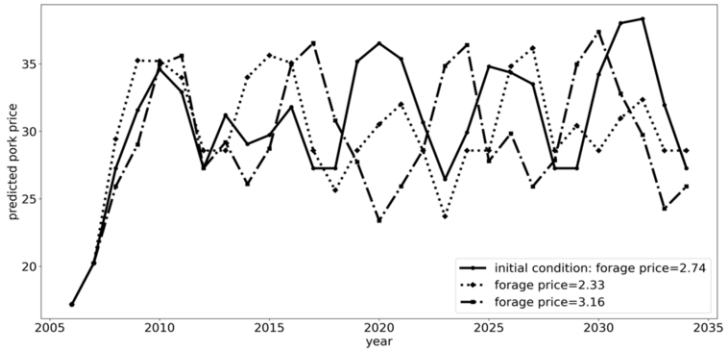

Fig. 6. The comparison of predicted price between different forage prices

Patterns in different forage prices are obviously different. Thus, the model is sensitive to the change in forage price.

4.3.2 Female Piglets' Price.

The mean and the standard deviation of the female piglets' price are ￥37.44 per piglet and 22.51, respectively. As the same manipulation on the forage price, the sensitivity analysis on the female piglets' price considers two conditions. The first assumes the price equals the mean plus one standard deviation, and the other is the mean minus one standard deviation. The results are in Fig. 7.

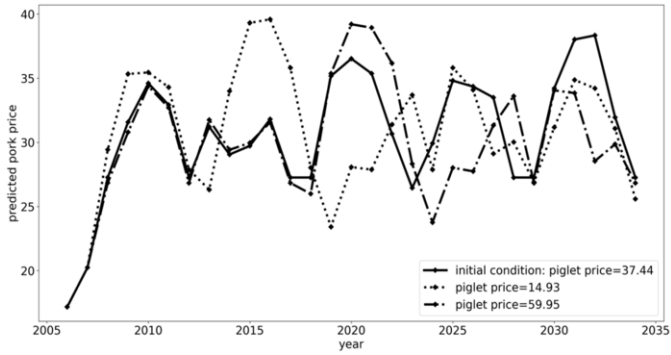

Fig. 7. The comparison of predicted price between three different piglet prices

Compared to patterns in different forage prices, price patterns with different piglet prices are tidier. From 2006 to 2023, predicted prices present similar cycles among these three conditions. Although patterns with different prices show different volatilities after 2023, their peaks and valleys appear nearly at the same time. Thus, the model generally has lower sensitivity to the change in female piglet price.

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5. Conclusion

This paper aims to simulate the pork price by mimicking the actual production process of pork. The simulation verifies the 5-years pork price cycle in China. The result shows that predicting pork prices by simulating the behavior of pig farmers and the age structure of female pigs is possible. The model predicts that the pork price will peak in 2026 and 2032. Because pork price indicates inflation, there might be inflation in these two years. The government can act in 2025 and 2031 to prevent this, like increasing the interest rate and releasing pork stocks. This study can be significant for the government to control the macroeconomy.

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