When cobweb meets oligopoly

China Agricultural Economic Review

Qianqian Zhang
College of Economics and Management, China Agricultural University, Beijing, China
Faqin Lin
Academy of Global Food Economics and Policy, College of Economics and Management, China Agricultural University, Beijing, China, and
Xiuqing Wang and Xian Xin
College of Economics and Management, National Agricultural and Rural Development Research Institute, China Agricultural University, Beijing, China

Received 3 January 2024
Revised 2 April 2024
Accepted 23 May 2024

Abstract

Purpose – The purpose of this paper is to present an oligopolistic version of the cobweb model that departs from the strict assumptions of perfect competition in the traditional cobweb model.

Design/methodology/approach – Introducing a model where *n* identical producers engage in Cournot competition, with output decisions influencing market prices. The paper retains the original assumptions of naive expectations and a linear model where price expectations of Cournot competitors are made simultaneously with production decisions. The investigation focuses on the model's behavior as the number of producers decreases or industry concentration increases. The authors also show empirical evidence when drawing the data from the pig sector in China and the USA.

Findings – The findings indicate that the cobweb model undergoes a transition from divergent to continuous and even convergent as the number of producers decreases or industry concentration increases. The incorporation of costs related to entry and exit from the market contributes to achieving a more stable equilibrium state.

Originality/value – The cobweb model has been primarily studied in an idealized market structure of perfect competition, and the assumptions that they share are not obviously appropriate to many agriculture markets. This study presents an alternative version of the cobweb model in an oligopolistic market that relaxes the strict assumptions of perfect competition. The authors show the dynamics of reduced competitor numbers or increased industry concentration on the convergence of the cobweb model based on subtle variations in parameters.

Keywords Oligopoly, Cobweb model, Competition

Paper type Research paper

1. Introduction

Considering the fluctuations in economic cycles, is there a time lag in the equilibrium adjustment between the quantity demanded, quantity supplied and prices in the market? The dynamics of supply adjustment followed by price changes is a classic concept in economic literature. The initial idea can be traced back to Moore's comprehensive economics in 1925 (Moore, 1925), while Schultz (1930), Tinbergen (1930) and Ricci (1930) independently provided mathematical formulations for it.

The etymology of "Cobweb Theorem" was first used by Kaldor (1934). Before that, Walras and Marshall proposed the concept of static market equilibrium, which assumes that supply

JEL Classification — B4, L1

Faqin Lin appreciates financial support from the National Natural Science Foundation of China (No: 72261147471 and 72073128 and 72061147002) and the major program of the National Social Science Fund of China (Research on the policy and mechanism of South-South agricultural cooperation to promote food security in China: 22&ZD086).

China Agricultural Economic Review

1756-137X
DOI 10.1108/CAER-01-2024-0005

and demand tend to reach a static balance (Holland, 1977). However, Moore (1925) observed that this does not align well with the reality of the moving equilibrium of supply and demand. Schultz (1928) referred to this as the "lag" phenomenon. Schultz's demonstration was the simplest, only providing the convergent type of cobweb model. Later, Tinbergen (1930) introduced both convergent and divergent types, and Ricci (1930) presented all three basic types currently used: convergent, divergent and continuous. The significance of the first wave of cobweb theory represented by these pioneers lies in advancing the evolution of classical economic theory (Geoffrey, 2023). It suggests that even under static conditions, if the equilibrium of prices and production is disturbed, it may not necessarily tend to return to normal. Instead, it can continue to cycle or worsen the disturbances.

The cobweb model is also one of the earliest models used to explain the dynamics of agricultural product prices. Similar to Schultz (1928), Ezekiel (1938) observed a high relevance between the cobweb model and "real-world" situations in agricultural markets, perhaps the most well-known being the "hog cycle". Due to the characteristics of near-perfect competition in agricultural markets and the inability to immediately adjust production decisions regarding planting areas and numbers of sows on hand, there exists a certain lag in adjustments. However, compared to lagged adjustments, it has been empirically proven that farmers tend to immediately adjust production decisions based on profitability. In other words, the realization of the first wave of the cobweb theory has been disrupted by various factors including naive price expectations (Coase and Fowler, 1935; Ezekiel, 1938; Kuznets, 1953; Myers *et al.*, 2010).

The evolution of the theoretical cobweb model in the second half of the 20th century was substantial, primarily focusing on how to identify and address factors of market imbalance and instability. Researchers have made efforts in two main areas: naive expectations and linear assumptions. On one hand, it would lead to systematic forecasting errors if producers made production decisions based on "irrational" naive price expectations. As such, improving expectations will therefore go beyond this simplistic economic environment. Nerlove (1958) studied the stabilizing effect of adaptive expectations, where producers make appropriate adjustments based on the past performance of their expectations. In Muth's (1961) seminal paper introducing rational expectations, he referenced the cobweb model, where producers have perfect foresight for the future. Brock and Hommes (1997) pioneered the concept of heterogeneous expectations, assuming that producers use different expectation rules to make optimal decisions and obtain different returns.

On the other hand, linear functions may adequately describe data within a narrow range typically covered by available time series, but there is substantial statistical evidence suggesting otherwise (Waugh, 1964). By incorporating nonlinear supply and demand curves, more comprehensive market stability solutions can be achieved (Samuelson, 1976). Subsequently, more researchers have utilized nonlinear dynamics in simulating cobweb models, such as Holt and Craig (2006) and Hommes (2011, 2018). Recently, studies have integrated two interconnected markets to investigate the cobweb model (Lundberg *et al.*, 2015; Chaudhry and Miranda, 2018). They found that policy interventions in one market can impact another, potentially disrupting overall market stability.

Despite the success and popularity of the cobweb model in the economic literature to analyze the supply and demand relation, however, the cobweb model has been primarily studied in an idealized market structure of perfect competition. While some studies on rational expectations or heterogeneous individual cobweb models have broken away from the assumption of homogeneous firms under perfect competition, they still do not consider the finite number of individuals, with the number of producers and consumers assumed to be infinite.

Despite their dominance in perfect competition, there are many issues in cobweb that the theories of perfect competition are inherently ill-fitted to address. The assumptions that they share, of an infinitely elastic supply of atomistic firms that are ex ante identical and do not engage in strategic interaction, are not obviously appropriate to many agriculture markets. Casual empiricism suggests that many industries are dominated by a small number of firms, and an increasing body of applied work shows that large firms account for a dominant share of markets. In other words, sectors are typically characterized by firms that are relatively large in the markets in which they compete.

For example, in China, large-scale pig enterprises have significantly expanded, among which the leading pig farmer, Muyuan Group, sold 61.201 million pigs in 2022, Wen's annual pig sales reached 17.9086 million and New Hope's annual pig sales reached 14.6139 million. Only Muyuan's annual pig sales accounted for 8.74% of the market share (CSIF, 2016-2022), indicating that the concentration of pig farming has further intensified and its influence on the pig market will become more apparent. Hence, the theory of oligopoly is suited to study the distinctive features of concentrated industries, and in particular, the persistence of price, as well as strategic behavior by firms and governments to preserve and enhance these dynamics of price adjustments.

Therefore, our paper contributes to the relevant literature by considering the cobweb model in an oligopolistic market setting rather than perfect competition. Particularly in an oligopolistic market, our model shows that the instability of the cobweb model, as the number of Cournot competition firms increases. However, for simplicity, we retain the assumptions of naive expectations, linear supply and demand curves. The results indicate that, first, as the number of firms decreases and industry concentration increases, there is a greater likelihood of convergence in the cobweb model. Second, if there are no barriers to entry and exit for firms, it actually exacerbates market instability. The results are robust when we introduce a perfect competitive market, but the number of firms are not infinite.

The rest of the paper is as follows. In Section 2, we introduce a linear supply curve in an oligopolistic market, where firms' decisions impact the market price. Section 3 discusses the cobweb model in a Cournot competition market. We revisit the cobweb model within the context of perfect competition, assuming the number of firms are not infinite and describing a perfect competitive market comprising innumerable homogeneous firms in Section 4. Section 5 shows empirical evidence using data from the pig industry in China. Section 6 concludes the paper.

2. Oligopolistic market supply curve

The typical market supply curve is derived by aggregating the individual supply curves of firms, which are based on the principle of profit maximization. When firms act as price takers, it means that each firm faces a horizontal demand curve. The quantity of output chosen by each firm does not affect the market price. Therefore, the marginal cost curve of each firm represents its supply curve. By summing up these individual supply curves, we obtain the industry's supply curve, which corresponds to the aggregated marginal cost curve.

In contract, firms' output decisions have varying degrees of influence on market prices in imperfectly competitive markets. They face a downward-sloping demand curve, also known as a residual demand curve, instead of a horizontal one. In Cournot competition markets, each firm chooses its optimal output level based on the output choices made by its competitors, aiming to maximize profit along the residual demand curve. As a result, each firm ultimately reaches an equilibrium output level, collectively determining the industry's price level. By summing up the optimization decisions of these firms, we can derive a strategic supply curve for oligopolistic markets that is similar to the supply curve observed in perfectly competitive markets. This curve is commonly referred to as the "strategic supply curve" due to its sensitivity to firms' strategic behavior.

Assuming there are N identical firms with a production cost function of

$$C(Q) = \frac{1}{2}\beta_1 Q^2 + \beta_2 Q \quad (1)$$

this quadratic cost function implies a linear marginal cost curve. If these N identical firms engage in the Cournot competition, they will have the same marginal cost $mc_i = mc_1 = mc_2 = \ldots = mc_n = mc$ and conjecture elasticity $\theta_i = \theta_1 = \theta_2 = \ldots = \theta_n = \theta$ (i.e. the percentage increase in industry output when a firm increases its output by 1%). The marginal cost (mc) and conjecture elasticity (θ) are the same for all firms. Furthermore, the conjecture elasticity is equal to the market share of each firm in the Cournot competition, which can be expressed as $\theta_i = \frac{\partial Q}{Q} / \frac{\partial q_i}{q_i} = \frac{\partial Q}{\partial q_i} \cdot \frac{q_i}{Q} = S_i = \frac{1}{n}$. The conjecture elasticity under Cournot competition reflects the degree of market concentration. When $\theta = 0$, it represents perfect competition. As θ ranges between 0 and 1, indicating different levels of oligopoly, culminating in a complete oligopoly when $\theta = 1$.

The profit maximization formula for Cournot competitor i can be expressed as:

$$\frac{P - mc_i}{P} = \frac{\theta_i}{\eta} \quad (2)$$

mc_i represents marginal cost, while η refers to the absolute value of market demand elasticity. Under the assumption of homogeneity, we can have:

$$mc_1 = mc_2 = \ldots = mc_n = mc \quad (3)$$

$$\theta_1 = \theta_2 = \ldots = \theta_n = \theta = \frac{1}{n} \quad (4)$$

So, we can get:

$$\frac{P - mc_i}{P} = \frac{P - mc}{P} = \frac{\theta}{\eta} \quad (5)$$

where, $\frac{\theta}{\eta} = L$ represents the Lerner index, which reflects the degree of market power.

$$P = \lambda \cdot mc \quad (6)$$

$$\lambda = \frac{1}{1 - L} = \frac{1}{1 - \frac{\theta}{\eta}} \quad (7)$$

λ represents the mark up, which is the cost pass-through multiplier.

Due to $mc_i = \frac{\partial C}{\partial q_i} = \beta_1 q_i + \beta_2$, after substituting it in (6) results in

$$P = \lambda(\beta_1 q_i + \beta_2) \quad (8)$$

which can be written as another form:

$$q_i = -\frac{\beta_2}{\beta_1} + \frac{1}{\lambda} \cdot \frac{1}{\beta_1} \cdot P \quad (9)$$

By summing up the supply curves of each firm, the industry's aggregate strategic supply curve:

$$Q=\sum_{i=1}^{n}q_i=-\frac{\beta_2\cdot n}{\beta_1}+\frac{1}{\lambda}\cdot\frac{n}{\beta_1}\cdot P=-\frac{\beta_2\cdot n}{\beta_1}+\left(1-\frac{\theta}{\eta}\right)\cdot\frac{n}{\beta_1}\cdot P \tag{10}$$

by rearranging the equation with price on the left-hand side:

$$P=\lambda\cdot mc=\lambda\left(\beta_2+\frac{\beta_1}{n}Q\right) \tag{11}$$

the above expression represents the "strategic supply curve" for the Cournot competitive market as a whole.

The derivation shows that the marginal cost curve of a firm is given by $mc_i=\beta_1 q_i+\beta_2$, where the slope is represented by c. It differs from the industry's overall marginal cost curve $mc=\beta_1\frac{Q}{n}+\beta_2$, where the intercept is β_2 and the slope is $\frac{\beta_1}{n}$. Since $Q=nq_i$, $q_i=\frac{Q}{n}$.

$\lambda=1$, $P=mc$ represents the supply curve for perfect competition
and
$\lambda\neq 1$, $P\neq mc$ represents the supply curve for oligopolistic competition, respectively.

3. Cobweb in cournot market

Assuming that the market demand curve is linear under the quadratic cost function, the strategic supply curve is also linear. Therefore, we study the cobweb model under the conditions of linear demand and linear supply.

$$Q=\alpha_1-\alpha_2 P \tag{12}$$

Assuming that Cournot competitors base their decisions on naive expectations about prices when choosing the output for the next period:

$$P_t^e=P_{t-1} \tag{13}$$

It should be noted that the previous cobweb models were all based on perfect competition, assuming that firms are price takers and make decisions solely based on price expectations, seemingly unaffected by other factors in determining prices. In reality, the supply curve in perfect competition appears to be the marginal cost curve, where the decision process behind it is that prices equal marginal costs. Prices and quantities are determined simultaneously, and when making price expectations, one must consider that changes in their own production will not affect prices. This actually indicates that price expectations are inseparable from considerations of one's own production characteristics and those of competitors. When Cournot competitors make decisions, they engage in quantity competition and choose the quantity that maximizes their own profits given their competitors' choices. Once the decisions on quantities are made and produced, they also determine the market price. The determination of quantity and price happens simultaneously. Therefore, Cournot competitors' price expectations are a process that simultaneously considers quantity choices. Price expectations are made in conjunction with the corresponding quantity decisions.

Market demand curve:

$$Q_t=\alpha_1-\alpha_2 P_t, or$$

$$P_t = \frac{\alpha_1}{\alpha_2} - \frac{1}{\alpha_2}Q_t \tag{14}$$

Strategic supply curve:

$$Q_t = -\frac{\beta_2 n}{\beta_1} + \frac{n}{\lambda\beta_1}P_{t-1}, or$$

$$P_{t-1} = \lambda \cdot mc = \lambda\left(\beta_2 + \frac{\beta_1}{n}Q_t\right) \tag{15}$$

When supply equals demand in period t, we obtain:

$$\alpha_1 - \alpha_2 P_t = -\frac{\beta_2 n}{\beta_1} + \frac{n}{\lambda\beta_1}P_{t-1} \tag{16}$$

derive a difference equation:

$$P_t - \frac{-n}{\lambda\alpha_2\beta_1}P_{t-1} = \frac{\alpha_1\beta_1 + \beta_2 n}{\alpha_2\beta_1} \tag{17}$$

The complementary function of (17):

$$P_A(\mathrm{t}) = \mathrm{A}\left[-\frac{1}{\lambda}\cdot\frac{n}{\alpha_2\beta_1}\right]^t \tag{18}$$

The complementary function has a particular solution:

$$\overline{P_t} = u \tag{19}$$

where u is an undetermined constant. Using (17):

$$u = \frac{\alpha_1\beta_1 + \beta_2 n}{\alpha_2\beta_1 + \frac{n}{\lambda}} = P_e \tag{20}$$

is obtained. Note that this is exactly the price of the static equilibrium. As such, the general solution to the difference equation is as follows:

$$P_t = \mathrm{A}\left[-\frac{1}{\lambda}\cdot\frac{n}{\alpha_2\beta_1}\right]^t + P_e = \mathrm{A}\left[-\frac{\frac{n}{\lambda\beta_1}}{\alpha_2}\right]^t + P_e \tag{21}$$

where α_2 is the slope of the demand function and $\frac{n}{\lambda\beta_1}$ is the slope of the strategic supply curve.

There are essentially two possibilities for the initial price dynamics:

(1) If $P_0 = P_e$, then $P_t = P_e$, and the price remains constant at P_e;

(2) If $P_0 \neq P_e$, then P_t t will exhibit divergent, oscillatory or convergent oscillations. Only when:

$$\lim_{t\to\infty} P_t = \lim_{t\to\infty}[P_A(\mathrm{t}) + P_e] = P_e \tag{22}$$

will the price tend to stabilize. The condition for this is $\left|-\frac{1}{\lambda}\cdot\frac{n}{\alpha_2\beta_1}\right| < 1$, indicating a convergent trend toward stability. Specifically speaking:

① If $\left|-\frac{1}{\lambda}\cdot\frac{n}{\alpha_2\beta_1}\right| < 1 \Rightarrow \mathrm{n} < \lambda\alpha_2\beta_1$, P_t converges toward P_e;

② If $\left|-\frac{1}{\lambda}\cdot\frac{n}{\alpha_2\beta_1}\right| = 1 \Rightarrow \mathrm{n} = \lambda\alpha_2\beta_1$, P_t oscillates cyclically around P_e;

③ If $\left|-\frac{1}{\lambda}\cdot\frac{n}{\alpha_2\beta_1}\right| > 1 \Rightarrow \mathrm{n} > \lambda\alpha_2\beta_1$, P_t diverges.

In the case of perfect competition $\lambda = 1$, $\frac{n}{\beta_1} < \alpha_2$ is the condition for convergence.

Due to $\lambda \geq 1$, $\frac{1}{\lambda}$ is less than or equal to 1. Therefore, the presence of the cost markup multiplier (λ), which represents imperfect or oligopolistic competition, makes it easier to achieve the conditions for convergence.

Similarly, the presence of the number of firms (n) makes it easier to meet the convergence conditions when n is smaller. In other words, the existence of n and λ reveals an increase in market concentration. An increase in $\frac{1}{n}$ (decrease in the number of firms) and a higher cost markup multiplier λ (indicating stronger market power) make it easier to achieve convergence conditions compared to perfect competition.

In summary, an increase in market concentration contributes to price stability. With a transition from a large number of firms to a smaller number, the intrinsic dynamics of the market can shift from divergence to cyclic oscillations and even convergence. Naturally, the corresponding equilibrium price will also increase. As λ increases (n decreases), the slope of the strategic supply curve becomes steeper, which further facilitates convergence.

In the case of perfect competition ($\lambda = 1$), the convergence condition is $\frac{n}{\beta_1} < \alpha_2$. When $\lambda > 1$, or $\frac{1}{\lambda} < 1$, the convergence condition becomes $\frac{1}{\lambda}\cdot\frac{n}{\beta_1} < \alpha_2$, which is easier to achieve than $\frac{n}{\beta_1} < \alpha_2$, meaning it is more likely to be stable. From the condition $\left|-\frac{1}{\lambda}\cdot\frac{\frac{n}{\beta_1}}{\alpha_2}\right| < 1$, it can be seen that a decrease in N, indicating an increase in market concentration, not only increases the possibility of convergence by changing the slope of the industry's marginal cost curve ($\frac{n}{\beta_1}$) but also further strengthens the possibility of convergence by enhancing market power (λ, cost markup). Since $\lambda = \frac{1}{1-\frac{\theta}{\eta}} = \frac{1}{1-\frac{1}{n\eta}}$, as n decreases and $\frac{\mathrm{n}}{\beta_1}$ decreases, λ needs to increase.

Figure 1 illustrates the difference between the strategic supply curve under oligopolistic competition and the competitive curve under perfect competition. We can observe from the price dynamics that under perfect competition, even if the cobweb model of n firms exhibits a divergent state, there is a possibility of transitioning toward convergence if we introduce conditions of imperfect competition. By controlling the market and achieving a cost markup multiplier $\lambda > 1$, the potential for transitioning toward convergence exists. A larger value of λ facilitates the transition toward convergence and price stability.

4. The impact of concentration on price equilibrium in perfect competitive market

Even in the absence of a dominant oligopoly in the market, there is a possibility of transitioning from a divergent state to a convergent state as industry concentration increases due to a reduction in the number of firms. Consider a market where multiple relatively smaller forms operate without any oligopolist giant. These forms offer products or services with a certain degree of differentiation, primarily achieved through packaging or other similar

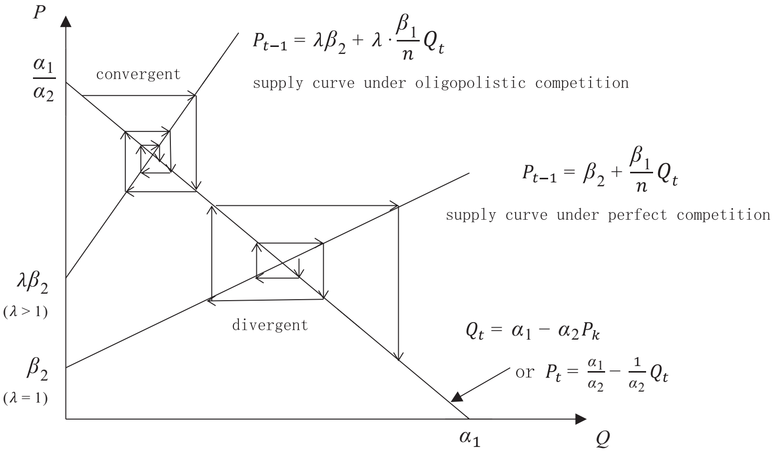


Figure 1. Cobweb price dynamics under oligopolistic and perfect competitions

Source(s): Authors' own creation

means. Each of them confronts its own individual demand curve and has the ability to alter its sales volume through price adjustments. However, their influence is insufficient to grant them pricing authority across the entire market, rendering them price takers in the market dynamics. We aim to illustrate that, with an increase in industry concentration, a situation akin to the oligopolistic market cobweb model is likely to reproduce.

The industry demand curve (but not the market demand curve) is still taken as linear as it was, recalling (12):

$$Q = \alpha_1 - \alpha_2 P \tag{12}$$

The cost function for each firm given by:

$$C(Q) = \frac{1}{2}\beta_1 Q^2 + \beta_2 Q \tag{23}$$

Assuming there are n identical firms, all of which are price takers and adopt naive expectations:

$$\overline{P_t} = P_{t-1} \tag{24}$$

The marginal cost of each firm is as follows:

$$mc_i = \frac{\partial C}{\partial q_i} = \beta_1 q_i + \beta_2 \tag{25}$$

Firms are price takers and perfectly competitive, then

$$p = mc_i \tag{26}$$

Hence, we get the firm's supply curve:

$$p = \beta_1 q_i + \beta_2, or$$

$$q_i = -\frac{\beta_2}{\beta_1} + \frac{1}{\beta_1}p \tag{27}$$

Aggregating the supply curves of the aforementioned n firms (27), the industry supply curve

$$Q = \sum_{i=1}^{n} q_i = -\frac{\beta_2 n}{\beta_1} + \frac{n}{\beta_1}P, or$$

$$P = \beta_2 + \frac{n}{\beta_1}Q \tag{28}$$

is obtained. The firm's supply curve and the industry supply curve have the same intercept but different slopes. Provided this, we present a linear cobweb model as follows:

$$Q_t^D = \alpha_1 - \alpha_2 P_t \Leftrightarrow P_t = \frac{\alpha_1}{\alpha_2} - \frac{1}{\alpha_2}Q_t \, Demand \tag{29}$$

$$Q_t^S = -\frac{\beta_2 n}{\beta_1} + \frac{n}{\beta_1}P_{t-1} \Leftrightarrow P_{t-1} = \beta_2 + \frac{n}{\beta_1}Q_t Lag\ Supply \tag{30}$$

$$Q_t^S = Q_t^D Market\ Cleaning \tag{31}$$

Using (29)–(31) and solving for the market clearing price yields:

$$\alpha_1 - \alpha_2 P_t = -\frac{\beta_2 n}{\beta_1} + \frac{n}{\beta_1}P_{t-1} \tag{32}$$

(D) (S) Similarly, we can derive the difference equation:

$$P_t - \frac{-n}{\alpha_2\beta_1}P_{t-1} = \frac{\alpha_1\beta_1 - \beta_2 n}{\alpha_2\beta_1} \tag{34}$$

and its complementary function:

$$P_A = A \cdot \left[\frac{-n}{\alpha_2\beta_1}\right]^t \tag{35}$$

Again, we get the particular solution of the complementary function:

$$\overline{P_t} = u \tag{36}$$

where u is still an undetermined constant. Using (34), which solves for:

$$u = \frac{\alpha_1\beta_1 + \beta_2 n}{\alpha_2\beta_1 + n} = P_e \tag{37}$$

Then the general solution to the difference equation hence:

$$P_t = A \cdot \left[\frac{-n}{\alpha_2\beta_1}\right]^t + P_e = A \cdot \left[\frac{-\frac{n}{\beta_1}}{\alpha_2}\right]^t + P_e \tag{38}$$

We get similar two possibilities for the initial price dynamics:

(1) If $P_0 = P_e$, then $P_t = P_e$, and the price remains constant at P_e and

(2) If $P_0 \neq P_e$, then P_t t will exhibit divergent, oscillatory or convergent oscillations.

Let us also record the condition for price stability of (22) for further use:

$$\lim_{t\to\infty} P_t = \lim_{t\to\infty}[P_A(\mathrm{t}) + P_e] = P_e \tag{22}$$

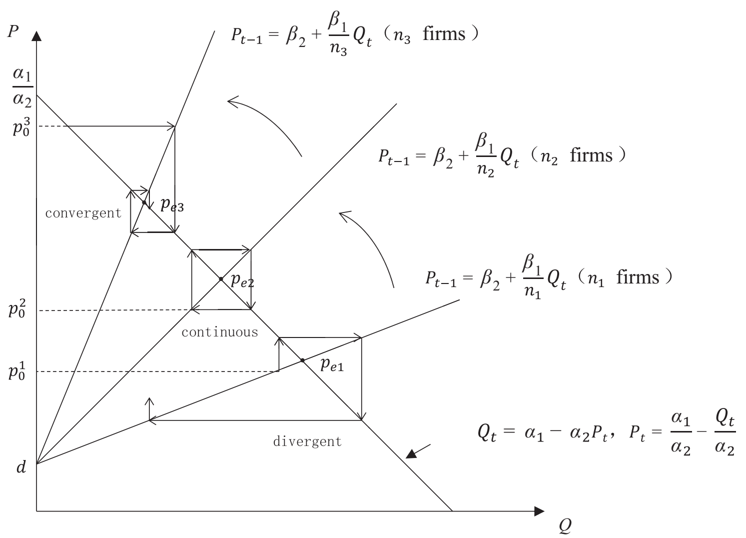
But now, the condition for this is $\left|\frac{-\frac{n}{\beta_1}}{\alpha_2}\right| < 1$ or $\frac{n}{\beta_1} < \alpha_2$.

Given c and b, that is, the slope of the market demand curve and the cost function, changes in n will result in different dynamic price trends. When $\mathrm{n} > \alpha_2\beta_1$, prices diverge; when $\mathrm{n} = \alpha_2\beta_1$, prices cycle; when $\mathrm{n} < \alpha_2\beta_1$, prices converge. In other words, as $\frac{1}{N}$ increases, indicating a decrease in the number of firms and an increase in concentration, the price dynamics may transition from divergence to cycling and eventually to convergence. As concentration increases to a certain extent (when n decreases below a certain threshold), industry prices tend to stabilize.

As we will see, as firms exit the market, price fluctuations tend to converge gradually. On the other hand, market supply increases when new firms enter the market, making price fluctuations more likely to diverge. This process of change is clearly depicted in Figure 2, providing insights into the dynamics of price variation where n represents the number of firms, which can be represented by the area of cultivated land and the number of sows in hand in agricultural production. The increase or decrease in n is equivalent to the entry or exit of firms in the industrial sector.

5. Empirical evidences

This section provides empirical evidence for our findings in the previous theoretical analysis that concentration makes the cobweb model more convergent. Convergent means the price fluctuation decreases. We hence use China and the USA's swine industry as an example since



Note(s): $n_1 > n_2 > n_3$, a decrease in the number of firms, causing a steeper slope of the industry supply curve represented by β_1/n

Source(s): Authors' own creation

Figure 2.
Cobweb price dynamics under perfect competitions with varying firm quantities

it stems from their prominence in employing cobweb models. The lagging production cycle makes it an ideal case for understanding the dynamics of the cobweb model. Moreover, China's pig industry encountered an explosive outbreak in the form of African swine fever in 2018. Similarly, even with years of research and experience in swine disease in the USA, there are still productivity losses in pig farming, which provided us with a unique setting, revealing the adaptability of the cobweb model in the face of external shocks.

5.1 Data sources

We obtained data from China's and the USA's pig sectors, with definitions and descriptions of the parameters provided in Table 1. The Chinese market share data is from the top 20 pork enterprises via the China Swine Industry Forum (CSIF, 2016-2022). For the USA, we used the United States Department of Agriculture (USDA) and Economic Research Service (ERS) data for swine inventory and farm size for (1997, 2002, 2007, 2012).

Chinese pork prices come from the China Agriculture Information Platform (CAIP, 2011-2021), while USA prices are from USDA (2013-2023). Both are adjusted using the Consumer Price Index (CPI): China's is based on 1975 (NBS, 2011-2021) and the USA's on 1982–1984 (BLS, 2013-2023).

Data on the impact of African swine fever in China are sourced from BrikBigData's (2011-2021) Swine Epidemic Severity Index, which reflects the mortality rates of pigs due to diseases. This index quantifies the severity based on the scope of the outbreak, intensity and the speed of transmission. A score below 0.25 indicates a normal level, while a score of 0.25 or above signifies a severe outbreak. The collection ceased in October 2021, which also limits the length of our Chinese dataset. The USA swine disease data are from the Swine Disease Reporting System (SDRS, 2013-2023) detection dashboards. The project has the goal to aggregate swine diagnostic data and report in intuitive formats. The antibody test results for swine diseases are updated quarterly, with the dataset calculated by simply adding the proportion of positive antibodies for all diseases. Data for the porcine epidemic diarrhea virus (PEDV) only starts from the second quarter of 2013, making it the starting point for our USA dataset.

The variable controlling the COVID-19 pandemic is derived from the World Pandemic Uncertainty Index (WPUI). The World Uncertainty Index website publishes these data (WUI, 2011-2023).

5.2 Concentration increase, swine disease and price dynamics

Before analyzing the trends of instability in pork prices, we would like to present some objective realities. The concentration levels in the pig industries of China and the USA are both increasing. Figure 3(a) illustrates the concentration ratio (CR20: top 20 Swine Farming Enterprises in China market share over the total national pig slaughter quantity) We can

Variable	Definition of variable	Frequency	Mean	ST.D.
$price_{CN}$	Chinese striped pork market price (Yuan)	Monthly	24.79	8.55
$price_{US}$	USA pork retail value (Cents)	Monthly	409.3	44.13
CPI_{CN}	Consumer Price Index in China (1978 = 100)	Yearly	2.43	0.13
CPI_{US}	Consumer Price Index in the USA (1982–84 = 100)	Monthly	2.57	0.23
$disease_{CN}$	China Swine Disease Severity Index	Monthly	0.25	0.13
$disease_{US}$	Random sampling positive antibody for swine diseases in the USA	Quarterly	1.03	0.09
Covid-19	World COVID-19 Pandemic Uncertainty Index	Monthly	2.45	5.78

Source(s): See details in 5.1 data sources, all the information is public

Table 1. The descriptive statistics and definition of time series variables

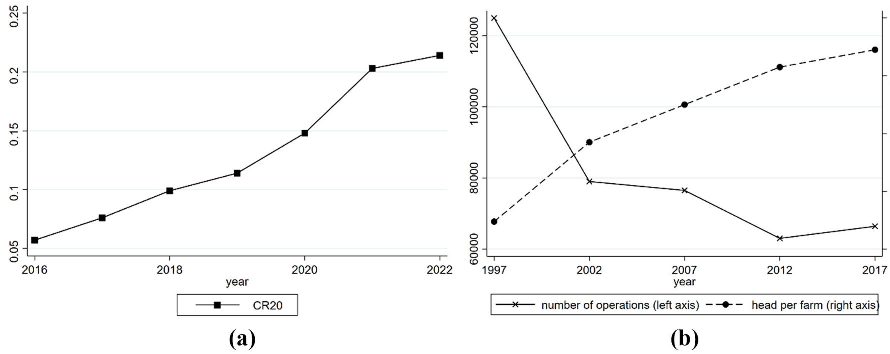


Figure 3.
Concentration levels in the pig industries of China (a) and the USA (b)

Source(s): See details in 5.1 Data Sources, all the information is public

clearly observe the increasing concentration in China's pig industry. A similar situation occurred in the USA. (Figure 3 (b)). The data include the number of operations with inventory, and the average farm size measured as the head of pigs per farm. With the number of pig farming operations is decreasing, the average number of pigs per farm is increasing. These evidence indicate the pig industry has lost the characteristics of a perfectly competitive market, manifested in the model as a decrease in the number of firms.

Pork prices show a lagged increase following the rise in the swine disease index. Figures 4 and 5 illustrate the situations in China and the USA. China experienced the most significant impact from pig diseases between September 2018 and June 2019, which coincided with the large-scale outbreak of African swine fever. After the pig disease index peaked, pork prices began to rise rapidly, reaching their first peak in November 2019. Subsequently, as the swine fever was brought under control, prices declined accordingly. This indicates a dynamic relationship between the pig disease index and pork prices, with a lag in their variations. The USA pig industry did not suffer from explosive shocks like China's. While there isn't as clear a relationship between the swine disease index and pork prices in the USA, lagged changes can still be observed.

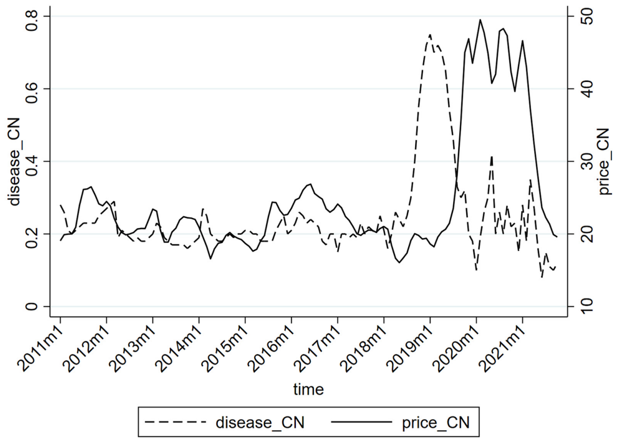
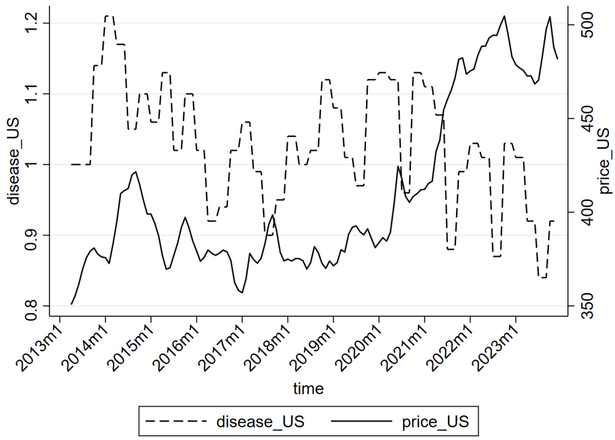


Figure 4.
Trends in Chinese swine disease and pork price

Source(s): See details in 5.1 Data Sources, all the information is public



Source(s): See details in 5.1 Data Sources, all the information is public

Figure 5. Trends in the USA swine disease and pork price

5.3 Data stationarity test (ADF test)

A necessary step before using time series data is to conduct a test for stationarity. The null hypothesis is that the examined time series variable contains a unit root. The test results are shown in Table 2. At the 5% significance level, the USA swine disease index rejects the null hypothesis, indicating no unit root and thus confirming the series as stationary. All other variables fail to reject the null hypothesis, suggesting the presence of a unit root. Further tests were conducted on the first-differenced series of nonstationary variables, which all rejected the null hypothesis, implying that the first-differenced series are stationary. Subsequent regressions are conducted on the stationary series.

5.4 Determination of lag length

Considering the lag in the adjustment of pork prices to swine disease outbreaks, we employ the information criteria method to determine the lag order. The test results for China are shown in Table 3. When the swine disease index in China is lagged by 3 periods, both Hannan-Quinn Information Criterion (HQIC) and Schwarz-Bayesian Information Criterion (SBIC) values are minimized. Applying the same method to test the swine disease index in the United States of America, the lag length is determined to be 24. Due to the length of the table, it is not displayed here. In the final regression, we will lag the swine disease indices of both countries by 3 periods and 24 periods.

	Original series				First-difference series			
Variable	ADF	5%	*P*-value	Stationary	ADF	5%	*P*-value	Stationary
$price_{CN}$	−1.098	−3.446	0.9294	no	−5.925	−3.446	0.000	yes
$price_{US}$	−1.261	−3.446	0.897	no	−6.669	−3.446	0.000	yes
CPI_{CN}	1.350	−3.446	1.000	no	−5.746	−3.446	0.000	yes
CPI_{US}	−0.356	−3.446	0.988	no	−6.122	−3.446	0.000	yes
$disease_{CN}$	−2.288	−3.446	0.441	no	−11.974	−3.446	0.000	yes
$disease_{US}$	−3.941	−3.446	0.011	yes	–	–	–	–
Covid-19	−2.118	−3.446	0.536	no	−10.947	−3.446	0.000	yes

Source(s): Authors' own creation

Table 2. Stationarity test results

5.5 Dynamic instability of pork prices

We still focus on determining whether the empirical evidence supports the conclusion of gradual convergence of price fluctuations as proposed in the oligopoly cobweb model. Therefore, we remove the growth trend over time and the impacts of potential shocks such as swine fever or COVID-19 pandemic using Equation (23):

$$ln\,Price_{i,t} = \omega_0 + \omega_1 time_i + \omega_2 time_i * time_i + \omega_3 covid19_{i,t} + \omega_4 disease_{i,t-T} + +month_t + \varepsilon_{it} \quad (23)$$

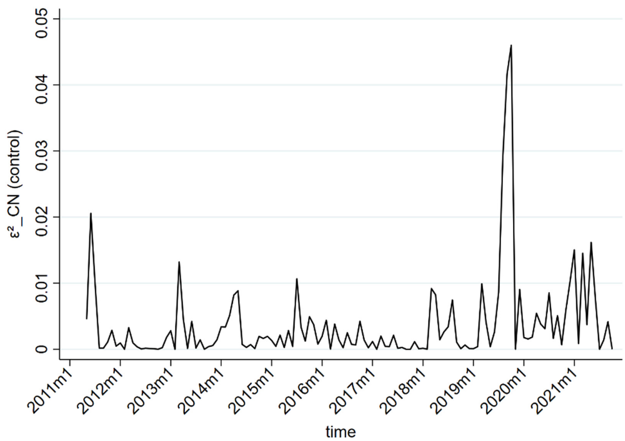
Adjust the pork prices for inflation using CPI first and then take the logarithm where applicable. ω_0, ω_0 and ω_2 represents the baseline. The control variables include $covid19_{i,t}$ and $disease_{i,t-T}$, along with the $month_t$ used to eliminate the seasonal effects of process changes. T represents the lag period: 3 for China and 24 for the USA. The squared residuals from the regression are reported in Figures 6 and 7. We can clearly see that the ε^2 of prices, which is the price fluctuation, in both China and the USA was gradually decreasing. Considering these findings above, we observe an inverse relationship between the trend of price volatility and industry concentration. When the number of firms decreases or industry concentration increases, the volatility of prices tends to converge, which is consistent to the findings of our theory (see Fig. 8).

After the COVID-19 pandemic, the price instability showed no regular pattern. We attributed this to two main reasons. First, the uncertainty index used for COVID-19

Table 3. Determination of lag length for China's swine disease index

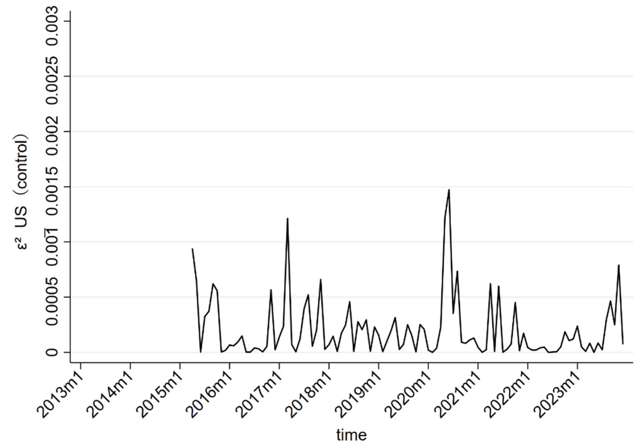
Lag	AIC	HQIC	SBIC
$disease_{CN}(-1)$	−2.503	−2.45	−2.367
$disease_{CN}(-2)$	−3.037	−2.945	−2.810
$disease_{CN}(-3)$	−3.257	−3.127*	−2.939*
$disease_{CN}(-4)$	−3.291	−3.125	−2.882
$disease_{CN}(-5)$	−3.316	−3.113	−2.816
$disease_{CN}(-6)$	−3.344*	−3.104	−3.104

Source(s): Authors' own creation



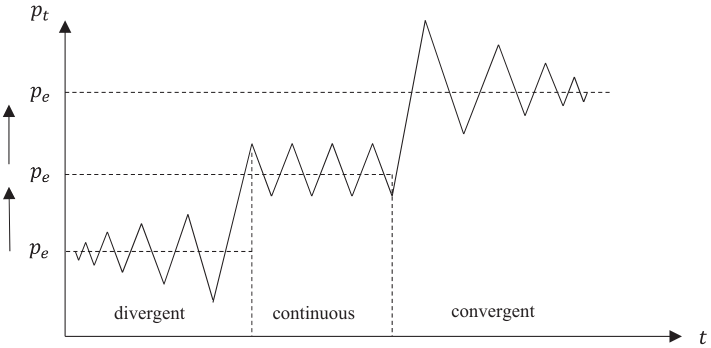
Source(s): Authors' own creation

Figure 6. ε^2 of pork prices in China



Source(s): Authors' own creation

Figure 7.
^{2} of pork prices in the USA



Source(s): Authors' own creation

Figure 8.
Dynamics of price when the number of firms n is decreasing

represents a global aggregate, failing to capture the distinct impacts of the pandemic on individual countries. Indeed, China and the USA had vastly different responses to the pandemic, both in terms of policies and public attitudes. Second, the uncertainty brought about by the COVID-19 pandemic significantly affected every link in the supply chain. Even as the world slowly recovers thereafter, the pig market may require more time to adjust.

As is well known, the market is incessantly exposed to a myriad of threats, encompassing climate change, natural disasters and international geopolitical tensions. External shocks wield the potential to precipitate a substantial escalation in market competition. Enterprises of larger scale demonstrate heightened adaptability, whereas smaller forms encounter substantial challenges and frequently withdraw from the market. The reduction in the number of firms n is influenced by exit and entry costs. The existence of such costs inhibits variations in n, while the absence of barriers contributes to a scenario where the numbers of firms randomly increase or decrease, thereby amplifying market instability. In oligopolistic market, the market leader possesses enhanced capabilities to influence prices and may engage in monopolistic pricing behavior. When we observe the trend shown in Figure 8, it indicates that the number of firms n is decreasing.

6. Conclusions

This paper delves into the variations encountered when the cobweb model meets oligopolistic competition. Initially establishing a simple model incorporating n identical firms engaged in Cournot competition, we establish a connection between market oligopoly and the cobweb model. As market dominance shifts toward fewer oligopolistic firms, the cobweb model demonstrates a greater propensity for convergence compared to conditions of perfect competition. Even in the absence of oligopolistic firms capable of manipulating prices and with numerous homogeneous small firms in the market, an increase in market concentration leads to a transition in the intrinsic dynamics from divergence to continuous and, ultimately, convergence. The likelihood of convergence in the model increases with higher market concentration, consequently resulting in an elevated equilibrium price.

We then use the data from China's pig industry to test the key predictions of the model. Results indicate that a decrease in the number of firms or an increase in industry concentration induces significant price fluctuations, signaling a departure from the anticipated stability. This volatility becomes more pronounced in the face of external shocks such as natural disasters or changes in international relations. Our findings underscore that the existence of costs associated with entry and exit from the market acts as a restraint on fluctuations in market concentration. Conversely, unhindered entry and exit exacerbate market instability. Therefore, we advocate for the implementation of moderate entry and exit regulation.

Our study contributes to the growing literature on the cobweb model. Diverging from existing research, our emphasis lies in examining the stability of the cobweb model as the number of Cournot competition firms increases. We retain the assumptions of naive expectations and linear supply and demand curves from the very traditional cobweb model, providing a foundation framework for future exploration of the cobweb model under nonperfect competitive conditions.

References

BLS (Bureau of Labor Statistics) (2013-2023), available at: https://www.bls.gov/cpi/

BrikBigData (2011-2021), available at: http://www.chinabric.com/index.html

Brock, W.A. and Hommes, C.H. (1997), "A rational route to randomness", *Econometrica*, Vol. 65 No. 5, p. 1059, doi: 10.2307/2171879.

CAIP (China Agriculture Information Platform) (2011-2021), available at: https://ncpscxx.moa.gov.cn/

Chaudhry, M.I. and Miranda, M.J. (2018), "Complex price dynamics in vertically linked cobweb markets", *Economic Modelling*, Vol. 72, pp. 363-378, doi: 10.1016/j.econmod.2018.02.012.

Coase, R.H. and Fowler, R.F. (1935), "Bacon production and the pig-cycle in great britain", *Economica*, Vol. 2 No. 6, pp. 142-167, doi: 10.2307/2548676.

CSIF (China Swine Industry Form) (2016-2022), available at: https://www.xumurc.com/main/ShowNews_75412.html

Ezekiel, M. (1938), "The cobweb theorem", *The Quarterly Journal of Economics*, Vol. 52 No. 2, pp. 255-280, doi: 10.2307/1881734.

Geoffrey, P. (2023), "Cobweb theory, market stability, and price expectations", *Journal of the History of Economic Thought*, Vol. 45 No. 1, pp. 137-161, doi: 10.1017/s1053837222000116.

Holland, T.E. (1977), "Marshall, Walras and the cobweb theorem", *The American Economist*, Vol. 21 No. 2, pp. 23-29, doi: 10.1177/056943457702100203.

Holt, M.T. and Craig, L.L.A. (2006), "Nonlinear dynamics and structural change in the U.S. hog—corn cycle: a time-varying STAR approach", *American Journal of Agricultural Economics*, Vol. 88 No. 1, pp. 215-233, doi: 10.1111/j.1467-8276.2006.00849.x.

Hommes, C. (2011), “The heterogeneous expectations hypothesis: some evidence from the lab”, *Journal of Economic Dynamics and Control*, Vol. 35 No. 1, pp. 1-24, doi: 10.1016/j.jedc.2010.10.003.

Hommes, C. (2018), “Carl”s nonlinear cobweb”, *Journal of Economic Dynamics and Control*, Vol. 91, pp. 7-20, doi: 10.1016/j.jedc.2017.12.007.

Kaldor, N. (1934), “A classificatory note on the determinateness of equilibrium”, *The Review of Economic Studies*, Vol. 1 No. 2, pp. 122-136, doi: 10.2307/2967618.

Kuznets, G.G.M. (1953), “Measurement of market demand with particular reference to consumer demand for food”, *Journal of Farm Economics*, Vol. 35 No. 5, pp. 878-895, doi: 10.2307/1233281.

Lundberg, L., Emma, J., Kristian, L., David, B. and Vilhelm, V. (2015), “A cobweb model of land-use competition between food and bioenergy crops”, *Journal of Economic Dynamics and Control*, Vol. 53, pp. 1-14, doi: 10.1016/j.jedc.2015.01.003.

Moore, H.L. (1925), “A moving equilibrium of demand and supply”, *The Quarterly Journal of Economics*, Vol. 39 No. 3, p. 357, doi: 10.2307/1882433.

Muth, J.F. (1961), “Rational expectations and the theory of price movements”, *Econometrica*, Vol. 29 No. 3, pp. 315-335, doi: 10.2307/1909635.

Myers, R.R.J., Sexton, R.R.J. and Tomek, W.W.G. (2010), “A century of research on agricultural markets”, *American Journal of Agricultural Economics*, Vol. 92 No. 2, pp. 376-403, doi: 10.1093/ajae/aaq014.

NBS (National Data Statistics of China) (2011-2021), available at: https://data.stats.gov.cn/easyquery.htm?cn=C01&zb=A0902&sj=2023

Nerlove, M. (1958), “Adaptive expectations and cobweb phenomena”, *The Quarterly Journal of Economics*, Vol. 72 No. 2, pp. 227-240, doi: 10.2307/1880597.

Ricci, U. (1930), “Die „synthetische ökonomie“ von henry ludwell moore”, *Zeitschrift für Nationalökonomie*, Vol. 11 No. 5, pp. 649-668.

Samuelson, P.P.A. (1976), “Optimality of sluggish predictors under ergodic probabilities”, *International Economic Review*, Vol. 17 No. 1, pp. 1-7, doi: 10.2307/2526061.

Schultz, H. (1928), *Statistical Laws of Demand and Supply with Special Application to Sugar*, University of Chicago Press, Chicago, pp. 27-39.

Schultz, H. (1930), “Der Sinn der Statistischen Nachfragen (The meaning of statistical demand curves)”, *Veröffentlichungen der Frankfurter Gesellschaft für Konjunkturforschung*, Vol. 10.

SDRS (Swine Disease Reporting System) (2013-2023), available at: https://fieldepi.org/domestic-swine-disease-monitoring-program/

Tinbergen, J. (1930), “Bestimmung und deutung von angebotskurven ein beispiel”, *Zeitschrift für Nationalökonomie*, Vol. 1 No. 5, pp. 669-679, doi: 10.1007/bf01318500.

USDA (United States Department of Agriculture) (2013-2023), available at: https://www.ams.usda.gov/

USDA (United States Department of Agriculture) and ERS (Economic Research Service) (1997, 2002, 2007, 2012), available at: https://www.ers.usda.gov/webdocs/publications/104437/err-308_summary.pdf?v=1171

Waugh, F.V. (1964), “Cobweb models”, *American Journal of Agricultural Economics*, Vol. 46 No. 4, pp. 732-750, doi: 10.2307/1236509.

WUI (World Uncertainty Index) (2011-2023), available at: https://worlduncertaintyindex.com/data/

Corresponding author
Xian Xin can be contacted at: xinxian@cau.edu.cn