Dynamic overcapacity modelling of early warning system for phosphorus fertilizer industry in China

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Abstract. In recent years, due to significant overcapacity in China's phosphorus fertilizer industry, the pressure of industrial capacity reduction issue has been existing for a long time. The study contributes to establish a dynamic early warning system of overcapacity to provide meaningful insight for optimizing managerial policies of phosphorus fertilizer industry in China. The dynamic early warning system includes a novel and comprehensive evaluation model, and the commonly used entropy method is applied to effectively demonstrate the degree of overcapacity. Then, the GM (1,1) grey model proposed provides future production scenarios. Several useful conclusions can be obtained. First, the overcapacity of phosphorus fertilizer has been existing for a long time and is characterized by periodicity, and more obviously, overcapacity deteriorate significantly in 2011 and 2015. Second, the greater threat would be the excessive growth and low utilization rate of new capacity of production, and the higher volatility of phosphorus fertilizer price but relatively low profit for phosphorus companies. Third, the significant increase of raw material price, labor and transportation cost and financing cost will restrict the development of the overall industry in the future, and we highlight the more comprehensive policies to consider the uncertainties in the overcapacity issue in the long term.

1 introduction

Overcapacity defines that the current production factors such as capital, labour and technology are not fully and reasonably utilized [1]. Since 2008, overcapacity has extended to various industrial industries, and restrict the healthy development of China's economy also potentially increase the macroeconomic risks in China. Market supply and demand, industrial organization, and economic cycles affect the problem of overcapacity in China's industries [2]. It is noteworthy that overcapacity involves institutional overcapacity [4], structural overcapacity and cyclical overcapacity [5], which were largely caused by over-investment in China`s industry [3]. Moreover, due to specific characteristics and complexity of each industry in China, all these factors could not explain the overcapacity issue.

In recent years, China's phosphorus fertilizer market is in a state of oversupply, and industrial overcapacity is prominent. First, in terms of production capacity, it has remained above 20 million tons of capacity since 2008. However, phosphorus fertilizer demand growth is limited. In comparison with 2008, the consumption only increased by 2.46% in 2018. Lietal. (2019) [6] predicted that the consumption of China's phosphorus fertilizer shows peak demand. Second, low level duplication construction and blind competition for upstream resources for phosphorus companies significantly influence the sustainable development. Moreover, the integration of upstream and downstream linkages is insufficient, and restrict the utilization of low- and medium-grade resources. Third, the excess supply of phosphorus fertilizer affects the supply security of China's phosphate resources and ultimately threatens the security of food supply [6]. More obviously, China's phosphate reserves account for only 4.57% of the world's phosphate reserves, but production accounts for 51.86% of the world's production(来源). Moreover, the export of phosphorus fertilizer(P_2O_5) increased by 10.9% in 2018 in comparison with 2017, and accounts for 32.1% of world`s production, and 34.1% of world’s export(来源). Long-term overcapacity has significantly affected the price of phosphorus fertilizer-related products, the declining profits, insufficient incentives for innovation, as well as widespread repetitive construction and disorderly competition among phosphorus companies.

Several contributions are as follows: First, the paper is the first study to quantitatively assess the overcapacity issue of China's phosphorus fertilizer industry for the first time. More precisely, we build a dynamic early warning system to indicate and predict the degree of overcapacity. Thus, this study extends literature to provide a useful insight for the subsequent strengthening of phosphorus fertilizer capacity optimization governance. Second, the measurement and prediction of excess capacity does not emphasize the accuracy, but rather provide early warning system to promote national and local governments can optimize legal, market environment and other policies to eliminate and restructure the overcapacity issue in China`s phosphorus industry. Finally, the study differs from other literatures with emphasizing the core manifestations being

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the constraint of scarce phosphate resources, the input composition, national demand elasticity, as well as the demand of other countries.

2 Literature review

Existing literatures on overcapacity issue is mostly set in the manufacturing and heavy and chemical industries, such as coal, iron and steel, and petrochemicals which are China's representative class of overcapacity industries [8]. More focus is placed on finding the causes of overcapacity from the supply side, such as the distortion of the industrial structure due to a long-standing imbalance in fixed asset investment, thus induced overcapacity [9]. Several studies analyse the causes of overcapacity from the demand-side perspective, both in terms of market demand and institutional mechanisms [10].

Bai Xuejie and Zhang Zhe[7] argue that the current overcapacity of heavy chemical companies is characterized by an inflated unbiased capacity utilization rate that will seriously underestimate the overcapacity, the main body of overcapacity is mainly backward production capacity. More obviously, state-owned enterprises in utilization rates of unbiased capacity are substantially higher than those of private and other ownership enterprises, but state-owned enterprises do not have a significant technological efficiency lead. Moreover, there is a risk of reducing unbiased capacity utilization due to backward production capacity. Yunyun Zhong [8] empirically investigates the influencing factors of overcapacity in 28 manufacturing industries in China using the GMM model. It confirms that overcapacity is widespread in China's manufacturing industries and has become increasingly serious in recent years. Market structure, industry structure, inefficient capital investment, permissive environmental pollution, and insufficient technological innovation are the factors that affect the manufacturing industry's production overcapacity. The priority of the current supply-side structural reform might not only resolve overcapacity, but optimize industry and market structure, environmental regulation, and technological innovation. The optimal policies might effectively alleviate overcapacity. He Weida and Qiu Linhui [11] confirm that the current overcapacity in China's steel industry is significantly manifested in the unreasonable industrial layout, distorted industrial structure, excessive energy consumption per unit product, excess capacity of low-end products and shortage of high-end capacity, etc. The supply-side reform put forward initiatives such as technological innovation, improving the industrial layout can improve the conversion rate of innovation, and accelerate the use of new technology, and might significantly alleviate current production overcapacity. Dong Changrui et al [12] used production data of steel industry in 30 provinces in China from 2008-2015, and a stochastic frontier analysis is applied to indicate overcapacity index and the factors which influence the overcapacity in the steel industry. The results show that Jiangsu, Shandong, Guangdong, Shanghai, Beijing and other regions show serious overcapacity; and government financial subsidies have a significant impact on the optimization of the steel industry. Overcapacity in the petrochemical industry is significantly manifested in the coexistence of aggregate production and structural problems, while the production structure within the industry and product structure cannot meet the demand of industrial upgrading [13]. Zhang Zaixu and Liu Shuaishuai[14] argue that China's petrochemical industry overcapacity is increasingly prominent, and establish a production capacity utilization evaluation system in China's petrochemical industry based on the entropy method to measure the comprehensive index of capacity utilization. An early warning baseline for overcapacity is set to evaluate the extent of overcapacity. The result shows capacity utilization and finished goods inventory turnover affect production overcapacity in the petrochemical industry largest.

The studies on the overcapacity of China's phosphorus fertilizer industry are limited and mostly qualitative analysis. For example, Ying Wang et al [15] qualitatively analysis the operation of China's phosphorus fertilizer industry in 2018, stating that in 2018 China's phosphorus fertilizer overcapacity in the industry has been alleviated compared to previous years, but still severe. A description of the world fertilizer supply and demand situation from 2016 to 2020 by the International Fertilizer Industry Association (IFIA) [16] show that global fertilizer production capacity has grown significantly, but world fertilizer demand has not expanded accordingly, and overcapacity will persist for a long time in the coming years. Yuqi (2020) [17] argues that supply-side structural reform has significantly improved the operating efficiency of the phosphorus fertilizer industry, but overcapacity, fierce competition within the market and the lack of downstream demand significantly restrict the healthy development of the phosphorus industry in China.

In summary, overcapacity is a prominent problem in the operation of China's macroeconomic management. For the specific industry of overcapacity of the peculiarities and complexity, supply-side management and demand management cannot effectively resolve overcapacity issue. This study firstly construct a comprehensive capacity utilization system for the phosphorus fertilizer industry based on the entropy method to quantify the level of overcapacity, then a grey prediction model is used to predict production capacity. The dynamic early warning system of the overcapacity of China's phosphorus fertilizer industry might help to provide a baseline of the overcapacity and develop policies to adjust the overcapacity and internal structure of the industry.

3 Methods

3.1 The entropy value method

A comprehensive evaluation system is needed to be assigned reasonable and appropriate weight to each indicator. This study uses the entropy value method which has higher accuracy for weight determination compared with e subjective methods such as Delphi and AHP method. The entropy value method is an information theory concept that explains the multiple amounts of

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information contained in the uncertainty of a random event. The method emphasizes the comprehensive level of measurement of multiple index systems, which is more suitable to reflect the level of industrial capacity utilization from multiple perspectives[18].The entropy value method is confirmed with objective, quantitative, and suitable to evaluate systematic response to current phosphorus fertilizer industry. The method can eliminate the significant differences effectively among.

3.1.1Data processing in polarization

Assuming that there are n years to observe and a total of m indicators, then x_{ij} is the jth annual observation of the i-th indicator $(i = 1,2,3,\cdots,m; j = 1,2,3,\cdots n)$, assuming indicator $X_i (i = 1,2,3,\cdots,m)$ of the anual observation is $X_{ij} (i = 1,2,3,\cdots,m; j = 1,2,3,\cdots n)$. Then the new data set obtained after standardization is denoted as Y. The standardization process:

When the indicator is positive

$$Y_{ij} = \frac{X_{ij} - \min(X_{1j},\cdots,X_{nj})}{\max(X_{1j},\cdots,X_{nj}) - \min(X_{1j},\cdots,X_{nj})}$$

When the indicator is negative

$$Y_{ij} = \frac{\max(X_{1j},\cdots,X_{nj}) - X_{ij}}{\max(X_{1j},\cdots,X_{nj}) - \min(X_{1j},\cdots,X_{nj})}$$

3.1.2The weight of standardized Y_{ij} in this indicator is measured as P_{ij}:

$$P_{ij} = \frac{Y_{ij}}{\sum_{j=1}^{n} Y_{ij}} (i = 1,2,3,\cdots,m; j = 1,2,3,\cdots n)j$$

3.1.3The information entropy for indicator i is expressed as:

$$e_i = -\frac{1}{Ln(n)} * \sum_{j=1}^{n} p_{ij} * Ln(p_{ij})$$

3.1.4 Measurement of the transaction weights of the indicators

$$w_i = (1 - e_i) / \sum_{i=1}^{n} (1 - e_i)$$

3.2 Grey prediction model

Prediction methods include ARIMA time series model, neural network model prediction, and grey prediction model GM(1,1). Grey prediction model is used to present irregular distribution and small sample size. The mo emphasizes that all random quantities need to vary in a certain interval and time frame with grey processes rather than simply studying the statistical patterns and deriving their probability distributions, the grey quantities are treated by obtaining from an erratic dataset of the regularity sequence. The steps for the grey system GM (1, 1) model are as followings.

3.2.1 Step1.Accumulation of the original series

$$X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(n)\}$$

Doing a cumulative generation yields: $X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \cdots, x^{(1)}(n)\}$

Cumulative series make the data more regular and prepare for predictive modeling

3.2.2Development of grey forecasting models

differential equation (math.) $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$
a, b are constants

3.2.3Constructing a cumulative matrix B and a constant term vector Y_N

$$B = \begin{Bmatrix} -\frac{1}{2}[x^{(1)}(1) + x^{(1)}(2)] & 1 \\ -\frac{1}{2}[x^{(1)}(2) + x^{(1)}(3)] & 1 \\ \vdots & \\ -\frac{1}{2}[x^{(1)}(n-1) + x^{(1)}(n)] & 1 \end{Bmatrix}$$

$$Y_N = [x_1^{(0)}(2), x_1^{(0)}(3), \cdots, x_1^{(0)}(N)]^T$$

3.2.4Least squares solution of ash parameters

$$a \quad = [a, b]^T = (B^T B)^{-1} B^T Y$$

3.2.5solve differential equations

$$x^{\wedge(1)}(t+1) = \left(x^{(0)}(1) - \frac{b}{a}\right) e^{-at} + \frac{b}{a}, t = 1,2,3,\cdots,n$$

The equation is the predicted value of the cumulative series

3.2.6Original series prediction formula

$$x^{\wedge(0)}(t+1) = x^{\wedge(1)}(t+1) - x^{\wedge(1)}(t), t = 1,2,3\cdots,n$$

3.2.7Calculate the $x^{(0)}(t)$ minus $x^{\wedge(0)}(t)$ equals $x^{\wedge(0)}(t)$ and the relative error $e(t)$

$$\varepsilon^{(0)}(t) = x^{(0)}(t) - x^{\wedge(0)}(t)$$

$$e(t) = \varepsilon^{(0)}(t) / x^{(0)}(t)$$

3.2.8 Assessment

In order to ensure the reliability of the model to diagnose

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the model, a posteriori deviation test is generally performed.

Calculate the data deviation first

$$s_1^2 = \sum_{t=1}^{m} \left[x^{(0)}(t) - \bar{x}^{(0)}(t)\right]^2$$

and residual variances

$$s_2^2 = \frac{1}{m-1} \sum_{t=1}^{m-1} \left[q^{(0)}(t) - \bar{q}^{(0)}(t)\right]^2$$

Calculating the posterior ratio

$$C = \sqrt{s_2^2 / s_1^2}$$

Calculate the probability of error

$$P = \left\{\left|q^{(0)}(t) - \bar{q}^{(0)}(t)\right| < 0.6745 s_1\right\}$$

The model as a whole is then tested and diagnosed based on the posterior ratio c and the small error probability p.

4 Results

4.1 Evaluation indicator system

Based on the characteristics of China's phosphorus fertilizer industry, the principles of systematization, objectivity and accessibility, this study builds a capacity utilization evaluation system from four levels, including capacity utilization, operating efficiency, market demand and resource utilization, and selects the rate of change of new capacity, capacity concentration, apparent consumption/production, rate of change of price index, rate of change of phosphorus fertilizer sales margin, rate of change of export quantity, export unit price, phosphate ore production/phosphorus fertilizer production, which are eight indicators to scientifically and objectively measure the overcapacity (Table 1).

The dataset derived from mainstream data sources such as the National Bureau of Statistics and China Phosphate Compound Fertilizer Association. The rate of change of new capacity reflects the current capacity utilization status of the phosphorus fertilizer industry. The relative number of increases or decreases in production capacity caused by changes in investment. The industrial concentration, phosphorus fertilizer sales margin change rate, and price change rate are selected to reflect the business status of enterprises comprehensively. The indicator of production capacity concentration is the sum of the production of the top ten enterprises in China's phosphorus fertilizer production accounted for the proportion of the national phosphorus fertilizer production. We selected top ten companies in the phosphorus fertilizer industry from 2009-2018 in terms of capacity concentration. The rate of change of phosphorus fertilizer sales margin is the change in the ratio of phosphorus fertilizer sales profit to phosphorus fertilizer sales revenue in a certain period. The rate of change in the price index reflects the relative number of price trends and value magnitudes in the phosphorus fertilizer industry over a given period. In this paper, the price index of the phosphorus fertilizer industry from 2009-2018 is selected as the raw data for the calculation. The apparent consumption/production, the rate of change of export quantity, and the export unit price are selected to reflect the market demand situation comprehensively. The rate of change in the quantity of exports is the relative number of the trend and magnitude of phosphorus fertilizer export changes in a certain period. The export price is the unit price of phosphorus fertilizer exports, which reflects the price of China's phosphorus fertilizer exports to overseas. Phosphate ore production/phosphorus fertilizer production is used to measure the amount of phosphate ore consumed per unit of phosphorus fertilizer production in a given period of time.

Table 1. China's phosphorus fertilizer industry overcapacity comprehensive evaluation index system

System	Indicators	definition
Utilization of production capacity	Rate of change in new capacity(XZ)	Relative magnitude of increases or decreases in productive capacity due to changes in investment in fixed assets
business benefits	industrial concentration()	The combined output of the top ten phosphorus fertilizer production enterprises accounts for the proportion of national phosphorus fertilizer production
	Rate of change in price indices(JG)	Relative number of price trends and value magnitudes over time
	Rate of change in profitability(XL)	Changes in the ratio of profit from phosphorus fertilizer sales to revenue from phosphorus fertilizer sales
	Apparent consumption/production(BC)	Apparent consumption as a proportion of production, which objectively reflects market supply and demand.
market demand	Rate of change in volume of exports(CK)	Relative trends and ranges of phosphorus fertilizer exports
	export unit price(CD)	Phosphorus fertilizer export unit prices
Use of phosphorus resources	Phosphate ore production/phosphorus fertilizer production(KF)	Ratio of phosphate ore production to phosphorus fertilizer production

4.2 Evaluation result

The indicators of the rate of change in new capacity (XZ), capacity concentration (CJ), apparent consumption/production (BC), rate of change in price index (JG), phosphorus fertilizer sales margin change (XL), export volume change (CK), export unit price (CD). Phosphate ore production/phosphorus fertilizer production (KF) was first standardized by the extreme value method to construct a comprehensive index system of the original dataset (Table 2). The normalized data will eliminate the scale effects and variance size factors, and the normalized data are denoted as BXZ, BCJ. BBC, BJG, BXL, BCK, BCD, BKF, and the processed data is based on the entropy value method. The weights of the indicators were measured for the standardized processed data, with weights of 0.055 for BXZ and 0.055 for BCJ. 0.134, BBC has a weight of 0.116, BJG has a weight of 0.193, BXL has a weight of 0.048, BCK's weight is 0.137, BCD's weight is 0.18, BKF's weight is 0.137 and the weights are multiplied to obtain the equation for the composite index (lc) for each year.

l c=0.055BXZ+0.134BCJ+0.116BBC+0.193BJG+0.048BXL+0.137BCK+018BCD+0.137BKF

Based on the equation to calculate the overcapacity measurement index of China's phosphorus fertilizer industry from 2009-2018 (Figure 1).

Table 2. Standardized indicators for measuring overcapacity of phosphorus fertilizer in China

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
BXZ	0.055	0.000	0.166	0.221	0.503	0.448	0.735	0.801	1.000	0.956
BCJ	0.407	0.880	0.958	1.000	0.476	0.675	0.912	0.251	0.000	0.633
BBC	1.000	0.957	0.626	0.361	0.534	0.740	0.393	0.000	0.167	0.100
BJG	0.712	0.196	0.204	0.266	0.057	0.340	1.000	0.138	0.000	0.078
BXL	0.621	0.000	1.000	0.780	0.770	0.798	0.931	0.846	0.945	0.873
BCK	0.000	0.384	0.564	0.105	0.174	0.335	0.340	0.135	1.000	0.270
BCD	0.200	0.411	1.000	0.804	0.418	0.323	0.200	0.003	0.000	0.123
BKF	1.638	1.711	1.662	1.729	1.652	1.730	1.732	1.707	1.785	1.785

In order to evaluate the degree of overcapacity scientifically and rationally, the study determines the warning interval based on the 3σ principle used by Li Xiuyuan [19]. The 3σ rule is based on the principle of normal distribution: when the data distribution is close to the standard line, the probability is higher, and vice versa. The probability is 31.74% if the deviation from the standard line is significantly more than one standard deviation, and 31.74% if the deviation is more than twice the standard line,the probability drops to 5%. If it exceeds 3 times the standard deviation, the probability P is less than 1%. The mean of the composite index, σ is the standard deviation of the composite index.

$$\text{Threshold} = \mu \pm \sigma$$

The two early warning lines form three intervals (+σ, 1], [-σ, +σ], and [0, -σ). Based on the phosphorus fertilizer industry in China, a composite index in the 0.523LC interval is defined as heavy degree of overcapacity. 0.339<LC≤0.523 interval is moderate of the degree of overcapacity; 0≤LC<0.339 is light and no excess interval.

According to the results, China's phosphorus fertilizer industry has significant overcapacity and the overcapacity is cyclically variable. It is more obvious and significant overcapacity in 2011 and 2015, and the rapid growth of new capacity with companies idling a large number of resource equipment and low capacity utilization coexist. Secondly, the phosphorus fertilizer industry concentration increased significantly alleviate overcapacity. Thirdly, the phosphorus fertilizer industry low-end capacity (such as monoammonium phosphate, phosphoric acid, phosphoric acid) lead to frequent price competition, structural contradictions within the industry, and the overall industry profit is declining. Finally, rising raw material prices, labour costs, transportation and financing costs significantly threaten the profit growth of the current phosphorus fertilizer industry.

4.3 Prediction result

The composite index model and GM(1,1) grey prediction model are used to forecast the composite index for China's phosphorus fertilizer industry in the next five years.

Step 1: Set the assumption conditions. Since there are many uncertain influencing factors in the phosphorus fertilizer industry in the next few years. In order to ensure the accuracy of the forecast value of the composite index. The following assumptions are China's economy continues to grow steadily, policy changes in the phosphorus fertilizer industry are modes, China's industrial restructuring is ongoing, and the phosphorus fertilizer industry is still an important industry in relation to food security.

Step 2: This study uses the 2009-2018 composite index as the raw data for the model.

Raw series are available.

$$X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(n)\}$$

The DPS software was used to derive the correlation coefficients and prediction model for the grey prediction model.

$$a = -0.058,\ b = 0.039$$

Short-term forecasting is appropriate when a < 0.3 and the time response function model is. $x^{(t+1)} = 0.752e^{0.058} - 0.668$

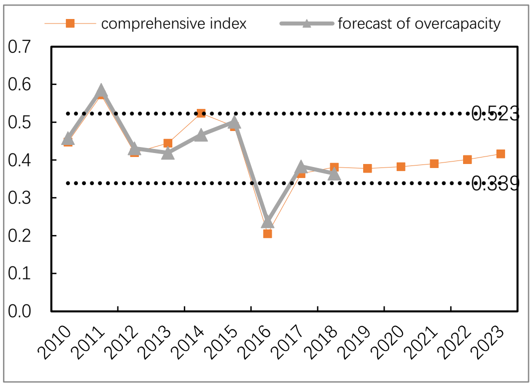

Fig 1. Comprehensive index and forecast of overcapacity in China's phosphorus fertilizer industry

The degree of fit between the actual model and the fitted value is high, the error between the two is small, C and P , and the model passes the test. The model is suitable for further forecasting. The phosphorus fertilizer industry composite index for the next five years from the DPS software through the forecasting model is 0.344, 0.354, and 0.383, 0.424, 0.477. Based on the early warning classification criteria above for the phosphorus fertilizer industry capacity early warning scenario for future years. Despite the overcapacity in the phosphorus fertilizer industry in the last two years with environmental pressure and supply-side reform after 2015, China's phosphorus fertilizer industry still has a relatively obvious overcapacity if without effective managerial policies , the phosphorus fertilizer industry will be increasingly accelerating the degree of overcapacity in the future based on the current capacity additions, business status, domestic and foreign market demand status.

5 Conclusion

The study constructs dynamic early warning system of overcapacity of China`s phosphorus fertilizer industry based on mainstream data sources from the National Bureau of Statistics and the China Phosphorus Compound Fertilizer Association. The results show that despite the current industrial concentration of the enhancement of the utilization of production capacity, but overcapacity is prominent and cyclical, with overcapacity particularly evident in 2011 and 2015 for China's phosphorus fertilizer industry. New production capacity grew too fast, and enterprises idle a large number of resources equipment and capacity utilization rate is low coexist. Meanwhile, the low-end capacity leads to frequent price competition within the industry, restricting the healthy and orderly development of the overall industry. The most warning is that the current industrial development is facing raw material prices and the increasing trend of artificial transportation and financing costs will significantly threaten the growth of the current industry's profit. It is estimated that in the next few years, the overcapacity issue of China's phosphorus fertilizer industry might remain an important issue that restricts the healthy development of the industry.

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