Open Journal of Social Sciences, 2022, 10, 28-43
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Efficiency Measurement of China's Water Supply Industry and Analysis of Its Influencing Factors

Chenyu Liu, Junjie Lin*, Wenqing Li

School of Finance, Anhui University of Finance and Economics, Bengbu, China
Email: *3202100183@aufe.edu.cn

How to cite this paper: Liu, C. Y., Lin, J. J., & Li, W. Q. (2022). Efficiency Measurement of China's Water Supply Industry and Analysis of Its Influencing Factors. *Open Journal of Social Sciences, 10,* 28-43.
https://doi.org/10.4236/jss.2022.1013004

Received: November 8, 2022
Accepted: December 5, 2022
Published: December 8, 2022

Abstract

Based on micro-data on water supply listed companies, the three-stage super-efficiency DEA model is used to measure the efficiency of China's water supply enterprises from 2016 to 2020, and tries to combine the evolutionary game method and the Gini coefficient for further analysis. The empirical results demonstrate that: 1) from the result of the first and three-stage DEA model, the efficiency values of sample enterprises show that there is still room for further improvement and development of enterprise efficiency; 2) according to the subsample analysis, the efficiency value of large-scale and high-financing enterprises is higher than that of small-scale and low-financing enterprises; 3) from the evolutionary game results, when large-scale enterprises players all chooses a high-financing strategy, and small-scale enterprises players choose low-financing strategy, the overall balance point of the game is reached.

Keywords

Water Supply Efficiency, Three-Stage Super-Efficiency DEA, Evolutionary Game

1. Introduction

Ensuring healthy drinking water and safe water is the top priority for the healthy development of a country. From 2005 to 2020, China's total water supply increased from 563.3 billion cubic meters to 581.29 billion cubic meters, an increase of 3.19 percent. The total domestic water consumption rose from 57.49 billion cubic meters to 86.31 billion cubic meters, an increase of more than 50 percent, far outpacing the increase in the country's total water supply. The key to ensuring domestic water for residents lies in grasping the operation characteristics of water enterprises, combined with the actual development of different enterprises to explore the efficiency of water supply enterprises, which is of great practical significance for the study of the overall residential water problem of the country (Zhao et al., 2021). In this paper, DEA and game theory model are used to empirically analyze the operation and development efficiency of China's listed water enterprises, and then the corresponding suggestions are put forward.

2. Literature Review

According to Lu Fusheng and Zhong Denghua's research on the development situation of China's water industry, there are many major problems in the water industry, such as uneven distribution of water resources in time and space, serious pollution of industrial water, old water supply equipment, low efficiency and no reasonable water price regulation mechanism (Lv & Zhong, 2013). The current literature research on the water industry is mainly conducted from the micro and macro levels respectively. For the measurement at the micro level, Liu (2016) adopted the Bootstrap-DEA model to measure the scale economy of listed water enterprises. Sun et al. (2016) used the traditional CCR and BCC-DEA model to compare and analyze the sample enterprises by dividing them into two types: private enterprises and state-owned enterprises. Explore the difference of enterprise efficiency under the two types of capital. As for the measurement of water supply efficiency at the macro level, Luo et al. (2020) adopted the DEA-Malmquist method to classify and compare the city-level water supply efficiency according to different regional distributions and the size of cities. The results showed that the difference in water supply efficiency gradually decreased from east to west, and from big cities to small cities. Li and Huang (2020) adopted stochastic frontier analysis to measure the water supply efficiency of Chinese cities. They used the data of 256 cities in China from 2009 to 2013 to measure the water supply efficiency, and analyzed the correlation between the four indexes that may affect the water supply efficiency and the water supply efficiency. The results showed that there were great differences in the water supply efficiency among cities. Most cities still have great room for efficiency improvement. Tskhai (2022) put forward a hypothesis that the factors affecting the efficiency of water enterprises are divided into two aspects: external, consumer factors and internal, enterprise factors. Then he used the growth pole theory as a research method to analyze the influencing factors of water supply efficiency in Russia. There are many methods to analyze the efficiency of water enterprises, among which DEA and SFA are widely used. Estruch-Juan et al. (2020) used 194 water enterprises as data samples to analyze and compare the characteristics of data processing of DEA and SFA in the efficiency measurement of water enterprises and the reasons for the difference in results. They came to the conclusion that the difference in results between the two methods was due to the different assumptions contained in the two methods.

In summary, through the analysis of provincial and municipal data, the macro analysis can obtain relatively complete data, and can intuitively analyze the difference phenomenon of water supply efficiency in different regions. For micro analysis, it is relatively difficult to collect data, but the results of analysis are of more realistic guiding significance for individual enterprises. At the same time, researches on water enterprises by existing scholars mostly adopt the traditional DEA model for analysis, ignoring the influence brought by the environment and random disturbance factors. In this paper, the three-stage super-efficiency DEA can better avoid the influence of this part (Fried et al., 2002).

In addition, this paper will try to combine the evolutionary game into the three-stage super-efficiency DEA, use the calculated efficiency value as the parameter value of the payoff matrix of the game, and then use the game equilibrium analysis method of the evolutionary game to give corresponding guidance and suggestions. The traditional evolutionary game analysis mostly adopts the direct subjective setting of the parameters of the game payoff matrix, but this has great subjective arbitrariness, because the final conclusion will change according to the different initial values of the previously set parameters (Wang & Meng, 2004). The combination of DEA and game theory can make up for the shortcomings of both sides.

3. Analysis Method

In this paper, three-stage super-efficiency DEA is used as the main data analysis method, and the evolutionary game analysis method is used for analysis. In order to combine the two analysis methods of DEA and evolutionary game, this paper divides the four cases of two strategies that can be chosen by two players in the traditional evolutionary game into four groups, measures the DEA efficiency of the four groups of data respectively, and then uses the measured efficiency value as the parameter value of the game payoff matrix. Then the evolution dynamic equation of the game payoff matrix with specific values is calculated and the Matlab numerical simulation is carried out to obtain the equilibrium point.

3.1. Three-Stage Super-Efficiency DEA

The analysis of three-stage super-efficiency DEA can be divided into three stages: In the first stage, the traditional super-efficiency DEA is measured for each sample enterprise. The measure model is the super-efficient-input-oriented-CCR model, and the formula of the model is shown in Formula (1). According to the measure results, the relaxation variable of each input index is further calculated (relaxation variable = original input value − input projection value). In the second stage, frontier 4.1 software was used to separate the relaxation variables measured in the first stage by using similar SFA method, combined with the selected environmental factors, and separated the management inefficiency, environmental factors, and random disturbance. For the separation formula of relaxation variables, this paper adopts the formula derived by Luo (2012) and Chen et al. (2014), as shown in Equation (2). In the third stage, after the management inefficiency is separated, the original input index is adjusted by combining the influence of environmental factors and random disturbance. The adjustment formula is shown in (3). Finally, the super-efficiency DEA is calculated for the adjusted input index.

First stage formula:

$$\begin{aligned} &\min \theta \\ &\text{s.t. } \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{ik} \\ &\quad \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ik} \\ &\quad i = 1,2,\cdots,m; r = 1,2,\cdots,q; j = 1,2,\cdots,n; j \ne k \end{aligned} \tag{1}$$

Second stage formula:

$$E(\mu \mid \varepsilon) = \sigma \cdot \left[\frac{\phi\left(\frac{\lambda\varepsilon}{\sigma}\right)}{\Phi\left(\frac{\lambda\varepsilon}{\sigma}\right)} + \frac{\lambda\varepsilon}{\sigma} \right] \tag{2}$$

Third stage formula:

$$\begin{aligned} X_{n_i}^{A} = x_{n_i} &+ \left[\max\left(f\left(z_i;\hat{\beta}_n\right)\right) - f\left(z_i;\hat{\beta}_n\right) \right] \\ &+ \left[\max\left(\nu_{n_i}\right) - \nu_{n_i} \right], \quad i = 1,2,\cdots,I; n = 1,2,\cdots,N \end{aligned} \tag{3}$$

3.2. Evolutionary Game

In the game analysis, this paper divides the sample enterprises into two groups according to their output, namely large and small, as two game parties, and then divides the proportion of interest-bearing liabilities in the total assets of the sample enterprises into two game strategies: high financing and low financing. The specific sample enterprise classification table and game revenue distribution diagram are shown in **Table 1** and **Figure 1**.

Suppose that in a large-scale enterprise, the proportion of high financing strategy is *y*, and the expected return is E_{y_1}; the proportion of low financing

Table 1. Sample enterprise classification table.

	large	Small
High financing	Xingrong environment	Hongcheng environment
	Zhongshan public	Qianjiang water conservancy
	Chongqing water	Wuhan holding
Low financing	Greentown water	Jiangnan water
	The first environmental protection	China's water
	Han blue environment	

Small \ Large	High financing	Low financing
High financing	A,a	B,b
Low financing	C,c	D,d

Figure 1. Game payoff matrix.

strategy is $1-y$, and the expected return is E_{y_2}, and the average return of the group is E_y. Suppose that in small enterprises, the proportion of high financing strategy is *x*, the expected return is E_{x_1}, the proportion of low financing strategy is $1-x$, the expected return is E_{x_2}, and the average return of the group is E_x. Specific calculations are as follows:

Large enterprises expect returns:

$$E_{y_1} = xa + (1-x)c$$

$$E_{y_2} = xb + (1-x)d$$

$$E_y = y\left[xa + (1-x)c\right] + (1-y)\left[xb + (1-x)d\right]$$

Small businesses expect profits:

$$E_{x_1} = Ay + B(1-y)$$

$$E_{x_2} = Cy + D(1-y)$$

$$E_X = x\left[Ay + B(1-y)\right] + (1-x)\left[Cy + D(1-y)\right]$$

According to the above expected returns, the dynamic equation of the evolutionary game can be further obtained as follows:

$$\frac{\mathrm{d}y}{\mathrm{d}x} = y(1-y)\left[x(a-c-b+d)+c-d\right] \tag{4}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = x(1-x)\left[y(A-C-B+D)+B-D\right] \tag{5}$$

Set the above dynamic equation as 0, it can be known that $\frac{\mathrm{d}y}{\mathrm{d}t}=0$ when $y=0,1,\frac{D-B}{A-B-C+D}$, then for the large-scale enterprise group, the evolutionary stable state is reached. And $\frac{\mathrm{d}x}{\mathrm{d}t}=0$ when $x=0,1,\frac{d-c}{a-b-c+d}$, then for small-scale enterprise group, it reaches the evolutionary stable state (Xie, 2001).

At this time, the practice in the existing literature is to directly make the assignment hypothesis for the parameters *a*, *b*, *c*, *d*, *A*, *B*, *C*, *D*, and then analyze the evolutionary game equilibrium point between groups according to the assigned parameter values. In this way, the parameter hypothesis is highly subjective and often affects the final analysis of the evolutionary equilibrium point (Xie, 2001). In this paper, the efficiency value measured by DEA is used as the initial set value of the game income parameters.

4. Selection and Introduction of Indicators

The DEA method may produce different conclusions for the selection of different input and output indicators in the same field (Shi et al., 2012; Huang et al., 2022). This paper will refer to the study of Bi et al. (2009) and Li and Gao (2014) on the selection of DEA input-output indicators of commercial banks, and select DEA indicators of water enterprises. This paper refers to the selection idea of three index classification methods for commercial banks, and selects capital input, raw material cost and total interest-bearing liabilities as input variables. Supply of tap water as output variable; the time of establishment of the company and the comprehensive interest rate as environmental variables. The details are as follows:

4.1. Investment Indicators

Capital input: Water enterprises are typical capital-intensive enterprises, that is, business development and capacity expansion mainly depend on the investment and construction of tangible assets, and non-current assets account for a large proportion of the total assets. The fixed assets of water enterprises mainly include buildings, pipe network assets, and machinery and equipment. Some of these fixed assets belong to other businesses operated by the enterprises, which will cause more interference to the study of water supply efficiency to be analyzed. And, in fact, water project construction and expansion of enterprise mainly rely on the franchise, signed with the local government for related plant under construction after the completion of the project construction will be divided into a franchise, the franchise on the accounting entries are classified as intangible assets, so the corresponding capital investment was divided into intangible assets. Similarly, part of intangible assets belongs to other businesses operated by water supply enterprises, such as sewage treatment or solid waste treatment. Therefore, no matter the selection of fixed assets or intangible assets, the influence of other business operations of the company on the occupation of corresponding assets must be taken into account. Considering this, capital input is chosen as the input variable, and the following formula is chosen for calculation (Bi et al., 2009):

$$\text{Capital input} = (\text{fixed assets} + \text{intangible assets}) \times \frac{\text{water supply revenue}}{\text{total revenue}}$$

Raw material cost: The more directly related cost variable of water supply raw material cost should be selected to analyze the impact of water supply efficiency. There are only some literatures that select this part mainly based on the main business cost. This variable is taken as the operating cost of the whole company, which includes many other business costs. Even considering that some water supply business only accounts for less than half of the company's operating business, the direct selection of the company's main business cost will cause great exogenous interference to the final analysis of water supply efficiency. Therefore, the raw material cost of the company's tap water supply business is selected as the input index, which can avoid the shortcomings of the main business cost.

Total interest-bearing liabilities: In addition to the capital input index selected in the input index, the amount of debt financing of enterprises also affects the operation and development of enterprises, because factory-related construction and investment in ongoing projects require external financing of enterprises to further improve the production capacity. For the calculation of interest-bearing liabilities, this paper mainly considers: Interest-bearing liabilities = Short-term borrowings + non-current liabilities due one year + other current liabilities + long-term borrowings + bonds payable, and other related interest-bearing liabilities disclosed in the company's annual financial statements.

4.2. Output Indicators

Tap water supply: Tap water supply is selected as the output variable, which can better form a direct input-output relationship with tap water raw material cost in the input index. Some researchers usually use net profit or operating income as an output index. If considering the relationship between net profit and revenue, the selection of the indicator may have a strong autocorrelation relationship, at the same time, the net profit and revenue are not only related to the enterprise the management efficiency, to a large extent to negotiate with the communication between the local government and enterprises obtain the average price of water also have relationship, if the two types of indicators for use directly as output indicators, there will be a large error. Therefore, the supply of tap water is selected as the output index (Li & Gao, 2014).

4.3. Environmental Variables

In this paper, the comprehensive interest rate and the company's establishment years, which are easy to collect and conform to the principle of selecting environmental indicators, are selected as environmental variable indicators.

Comprehensive interest rate: The company's financing cost is the main factor that restricts the size of the company's financing, and then affects the enterprise scale. For corporate financing cost, its value is usually not subject to the subjective influence of the company, and is mainly related to government subsidies or external credit rating agencies, which conforms to the selection principle of environmental indicators. The lower financing cost can promote the company to increase financing, expand the scale, improve efficiency and increase production. On the contrary, high financing costs will greatly restrict the expansion of the company's scale and the improvement of capacity and efficiency. Therefore, the comprehensive interest rate is chosen as the environmental indicator. The formula for calculating the comprehensive interest rate is as follows:

$$\text{Comprehensive interest rate} = \frac{\text{Annual interest expense}}{\text{Total interest-bearing liabiities}}$$

Years of establishment of the company: the establishment of the company more long more conducive to the company accumulated the experience curve, implementation technology progress, and also benefited the company and establishing long-term friendly and cooperative partnership in this industrial chain, so as to improve the efficiency of company management. Moreover, the age of establishment of the company also conforms to the principle of selecting environmental indicators.

5. Empirical Analysis

This paper is mainly based on the publicly released annual report data of each company as sample data. Before using the DEA model for measurement, it is necessary to confirm that the sample data meets a premise: that is, there is a significant positive correlation between the output index and the input index in the sample data, which is called isotonicity (Xiao et al., 2012). Therefore, before the empirical analysis, this paper first used the Pearson correlation analysis test to test the correlation of data. The calculated results are shown in **Table 2**. The correlation coefficients of the three input indexes corresponding to the output index of tap water supply are 0.8527, 0.8953, and 0.7290 in sequence, all of which are significant at the 1% significance level. Therefore, the selected data conforms to the assumptions.

5.1. The First Stage: DEA Super Efficiency Model Calculation

In the first stage, Matlab is used to measure the relative efficiency of the input and output variables of the selected sample enterprises according to the DEA super-efficiency model. The results are shown in **Table 3**.

According to the super-efficiency DEA results in **Table 3**, it can be seen that the average efficiency of the sample enterprises in 2018 showed a sudden increase,

Table 2. Input-output Pearson test results.

variable:	capital input	cost of raw material	liability with interest	tap water supply
capital input	1.000			
cost of raw material	0.7412***	1.000		
liability with interest	0.3993***	0.8380***	1.000	
tap water supply	0.8527***	0.8953***	0.7290***	1.000

***: It is expressed as significant at the 1% level, **: significant at the 5% level, *: significant at the 10% level.

Table 3. Measurement value of super-efficiency DEA in the first stage.

Year	Super efficiency means
2020	0.6625
2019	0.7009
2018	1.5583
2017	0.6875
2016	0.7509

which is because the input value of the total interest-paying liabilities in the sample enterprises in 2018 was low. At the same time, considering that the substantial reduction of interest-bearing liabilities will reduce the interest expense of the current year, so as to reduce the comprehensive interest rate in the environmental variables. Therefore, this can be eliminated to some extent in the third stage of analysis considering the influence of environmental factors.

5.2. The Second Stage: Separation of Management Inefficiencies

The following results are obtained by using frontier 4.1 software to regress the slack variables corresponding to the three input variables calculated in the first stage combined with the data of environmental variables, as shown in **Table 4**.

The results in **Table 4** show that the significance test of the maximum likelihood ratio is passed, which indicates that it is necessary to use SFA regression. According to the research of Luo (2012) and Chen et al. (2014) on management inefficiency, when γ is close to 1, it indicates that management inefficiency occupies an absolute proportion in the mixed error term, and the proportion of random disturbance is relatively small. The comprehensive interest rate in the environmental variables is negatively correlated with the slack variable of capital input, which indicates that the higher the comprehensive interest rate is, the lower the slack variable of capital input index is, and the higher the efficiency is. However, the slack variable parameter of the comprehensive interest rate for the input index of raw material cost and total interest-bearing liabilities is positive, which indicates that the higher the comprehensive interest rate is, the higher the slack variable of raw material cost and total interest-bearing liabilities will be, and the efficiency will be reduced. Similarly, for the company's establishment years, the higher the company's establishment years are, the higher the slack variable of the company's capital input will be, and the lower the slack variable of the raw material cost and the total amount of interest-bearing liabilities will be.

5.3. The Third Stage: Calculation of Input Adjustment Value

In the third stage, the three input variables after adjustment are brought back into the super efficiency DEA model of the first stage for calculation, and the results are shown in **Table 5**.

As can be seen from the data in **Table 5**, when the influence of environmental

Table 4. SFA regression results.

	capital input	Raw material cost	Total interest-bearing liabilities
Constant	−0.8324	−1.5429	−46.4201***
Comprehensive interest rate	−295.3945***	49.2638***	1917.7692***
Established years	0.5419***	−0.1453***	−1.607***
σ^2	525.6568***	9.9515***	5234.2544***
γ	0.9999***	0.9999***	0.9999***
LR test value	8.6921***	5.6668**	4.7706*

Table 5. Comparison of results of first-stage efficiency and third-stage efficiency.

Year	First-stage	Third-stage
	Efficiency value	Efficiency value
2016	0.7422	0.8711
2017	0.6875	0.7925
2018	1.5583	0.7894
2019	0.7009	0.8108
2020	0.6625	0.7955

factors and random disturbance is taken into account, the efficiency value of sample enterprises increases after the influence of environmental factors and random disturbance is excluded, except that the average value in 2018 decreased from 1.5583 to 0.7894. As can be seen from the data in Table 5, when the influence of environmental factors and random disturbance is taken into account, the efficiency value of sample enterprises increases after the influence of environmental factors and random disturbance is excluded, except that the average value in 2018 decreased from 1.5583 to 0.7894. But this is because the mentioned above, the 2018 sample companies into interest-bearing liabilities index is due for repayment for debt, makes the interest-bearing liabilities into greatly reduce the efficiency value of lead to spurt, and considering the comprehensive year-on-year decline in the adjustment of the interest rate environment variable, in the calculation of the third stage of indirect eliminating the influence of the part. For the whole sample enterprise, considering the establishment years of environmental variables and the comprehensive interest rate will become the factors restricting the efficiency growth of the enterprise, after removing these exogenous factors in the third stage, the average value of the overall efficiency of the sample enterprise will increase.

5.4. Sample Enterprise Efficiency Analysis from Different Perspectives

Even though the efficiency measurement in the third stage achieved a good increase in the mean efficiency, in the efficiency results of the third stage, except for the relatively high mean efficiency in 2016, the mean efficiency of other years still has a certain room for improvement. The sample enterprises will be further subdivided for better analysis (Zhao & Zhen, 2019).

Figure 2 is the comparison of the mean efficiency of enterprises differentiated according to the scale of tap water supply. It can be seen that, except in 2016, the mean efficiency of small-scale enterprises is roughly equal to that of large-scale enterprises, but in other years, the mean efficiency of small-scale enterprises is significantly lower than that of large-scale enterprises. It shows that in the capital-intensive industry such as the water industry, enterprises with scale advantage can achieve higher production and operation efficiency.

Figure 3 is the mean comparison of enterprise efficiency differentiated according to the proportion of interest-bearing liabilities in total assets. It can be seen that sample enterprises with a high financing ratio achieve higher average efficiency. Thus, may safely draw the conclusion that, for the water sector, appropriate take a high proportion of financing can better improve the efficiency of enterprise production and operation, because for water industry the utility industry, the company's business is relatively stable, good credit rating, external financing costs are low relative to other industries, The company can achieve the

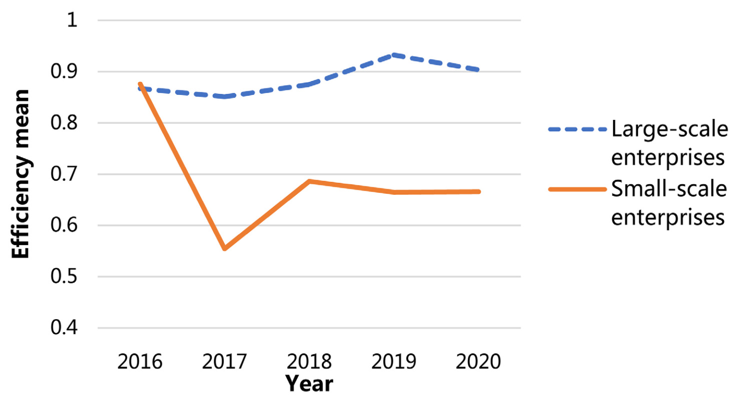

Figure 2. Comparison of the efficiency of large and small enterprises.

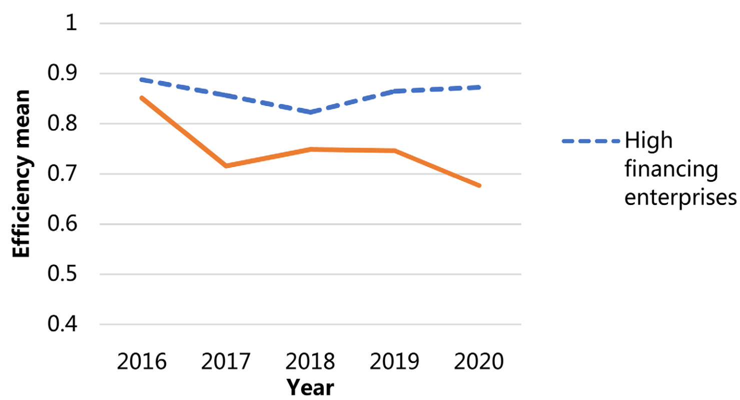

Figure 3. Efficiency comparison between high and low financing enterprises.

purpose of promoting production and efficiency through an appropriate increase of financing.

5.5. Evolutionary Game Analysis

In order to combine the empirical data analysis method of DEA, this paper divides the two strategies that can be selected by the two game parties in the traditional evolutionary game into four groups, and then measures the DEA efficiency of the four groups of data, and then uses the efficiency value measured as the parameter value of the game payoff matrix. The specific groups are shown as follows:

(High financing strategy for large enterprises, High financing strategy for small enterprises) = (0.8837, 0.9543).

(Low financing strategy for large enterprises, High financing strategy for small enterprises) = (0.9225, 0.8889).

(Low financing strategy for large enterprises, Low financing strategy for small enterprises) = (0.9273, 0.5594)

(High financing strategy for large enterprises, Low financing strategy for small enterprises) = (0.9439, 0.5821).

The above efficiency value results are expressed as: when game side A1 is a large-scale enterprise, the game side A2 is a small-scale enterprise, and both parties choose the same high financing strategy, the relative returns of the two are 0.8837 and 0.9543. In order to facilitate the next step of calculation, each data value is further processed and put into the game payoff matrix as shown in Figure 4.

Putting the parameter values into the dynamic Equations (4) and (5), the specific results are as follows:

$$\frac{\mathrm{d}y}{\mathrm{d}x} = y(1-y)\left[x(a-c-b+d)+c-d\right] = y(1-y)\left[0.42x+0.23\right] \tag{6}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = x(1-x)\left[y(A-C-B+D)+B-D\right] = x(1-x)\left[-0.56y-0.04\right] \tag{7}$$

Setting the above dynamic equation equal to 0 can obtain 5 equilibrium points, which in turn are:

$(y,x)=(1,1),(1,0),(0,0),(0,1),(-4/56,-23/42)$. Since y and x represent the proportion of two kinds of strategies chosen by the game player, the value range of y and x is [0,1]. Therefore, the negative points of y and x are omitted, and only four equilibrium points (1,1), (1,0), (0,0) and (0,1) are considered. In order to further analyze the evolution equilibrium point, the partial derivatives of y and x of the dynamic Equations (6) and (7) are calculated as follows, and the Jacobian matrix is obtained as follows:

$(1-2y)(0.42x+0.23)$	$0.42y(1-y)$
$-0.56x(1-x)$	$(1-2x)(-0.56y-0.04)$

After obtaining the Jacobian matrix, it judges the positive and negative of the determinant value of the matrix and the trace, so as to judge the evolutionary stable strategy (ESS) (Sun et al., 2021). By substituting the equilibrium point calculation one by one, it is determined that $y = 1$, $x = 0$ is the evolutionary equilibrium point of the evolutionary game, and the specific results are shown in **Table 6**.

In order to further analyze the process of the evolutionary game, this paper uses Matlab for numerical simulation analysis, as shown in **Figure 5**.

From the results of numerical simulation, the results obtained are consistent with the evolution equilibrium point analysis in **Table 6**, that is, when large-scale enterprises choose high financing strategy, while small-scale enterprises choose a low financing strategy, the evolution equilibrium point is reached. Large enterprises can usually obtain low financing costs, so as to expand their scale, increase productivity and improve efficiency; however, due to

Large / Small	High financing	Low financing
High financing	8.84,9.54	9.23,8.89
Low financing	9.44,5.82	9.27,5.59

Figure 4. Game payoff matrix.

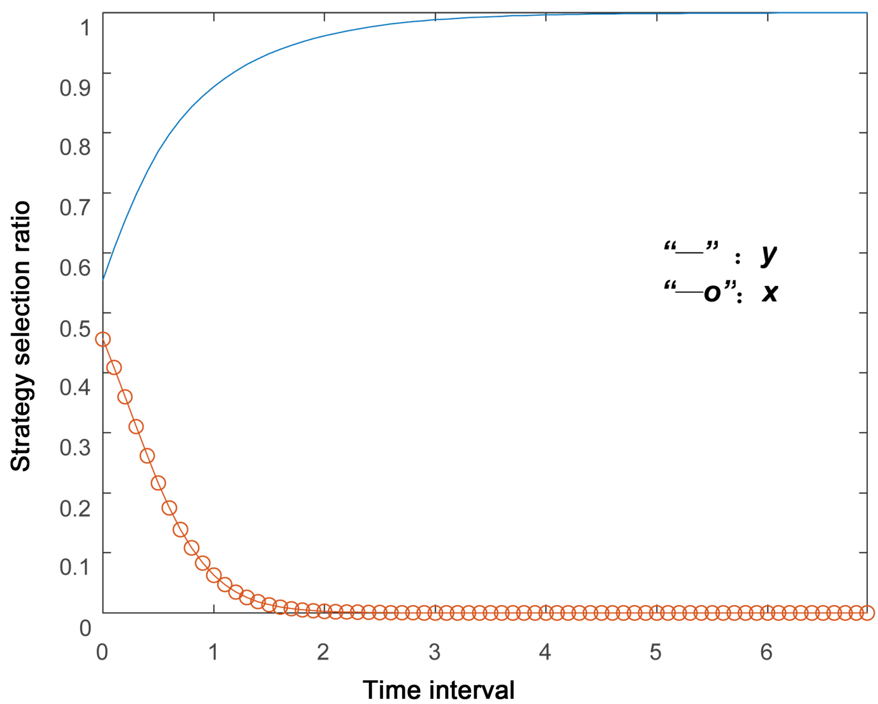

Figure 5. Numerical simulation of evolutionary game.

Table 6. Analysis of equilibrium points.

equilibrium points	Determinant (sign)	Trace (sign)	Stability
(1,1)	−	−	instability
(1,0)	+	−	ESS
(0,0)	−	+	instability
(0,1)	+	+	instability

the small scale, it is difficult for small-scale enterprises to obtain a good credit rating, and the high financing cost makes it difficult for small-scale enterprises to make profits, resulting in greater financial pressure. Finally, they will choose the most favorable strategy for themselves.

6. Conclusions and suggestions

6.1. Research Conclusions

According to the results of the super efficiency, DEA measurement in the first and third stages, the average efficiency of sample enterprises in each year still has a certain room for improvement. For better analysis, sample enterprises are divided into two groups according to their size and financing. The results show that large-scale or high-financing water utilities enterprises can achieve better production and operation efficiency. The analysis results of the evolutionary game show that the equilibrium point of the evolutionary game is when all the large-scale enterprises choose the high financing strategy and all the small-scale enterprises choose the low financing strategy.

6.2. Recommendations

1) The local government should attach importance to the promoting effect of technological innovation on the efficiency improvement of water enterprises and keep the introduction of regional scientific and technological talents and the increase of scientific research and innovation subsidies. Enterprises should promote the replacement of old and inefficient equipment, and adopt new and efficient equipment to better improve the operating efficiency of enterprises. Adequate and appropriate investment in scientific and technological innovation can achieve better performance improvement and achievement transformation.

2) There are significant differences in the efficiency development level of water utilities under different scales. In order to prevent the bifurcated efficiency development level within the industry, it is necessary to give full play to the leading role of large-scale water utilities, introduce the operation and management experience of high-quality enterprises, and accelerate the innovative development of small and medium-sized water utilities enterprises.

3) Through the guidance of the government, the merger and combination between suitable water enterprises can be promoted, which can not only give play to the economies of scale, improve efficiency and production, but also im-

prove the credit rating of enterprises and reduce the financing costs of enterprises by endorsing the advantages of scale.

Funded Project

Postgraduate Research Project of Anhui Province (YJS20210419); Universities Collaborative Innovation Project of Anhui (GXXT-2021-049).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Bi, G., Liang, L., & Yang, F. (2009). Study on the Selection of Input-Output Indexes for DEA Efficiency Evaluation of Commercial Banks. *Management Review, No. 6,* 10-16. (In Chinese)

Chen, W., Zhang, L., Ma, T., & Liu, Q. (2014). Research on the Three-Stage DEA Model. *Systems Engineering, No. 9,* 144-149. (In Chinese)

Estruch-Juan, E., Cabrera Jr., E., Molinos-Senante, M., & Maziotis, A. (2020). Are Frontier Efficiency Methods Adequate to Compare the Efficiency of Water Utilities for Regulatory Purposes? *Water, 12,* Article 1046. https://doi.org/10.3390/w12041046

Fried, H. O., Lovell, C. K., Schmidt, S. S., & Yaisawarng, S. (2002). Accounting for Environmental Effects and Statistical Noise in Data Envelopment Analysis. *Journal of Productivity Analysis, 17,* 157-174. https://doi.org/10.1023/A:1013548723393

Huang, K., Li, Y., Zhang, J., & Wei, Z. (2022). Study on Measurement of Collaborative Innovation Development of Electronic and Communication Equipment Manufacturing Industry and Its Influencing Factors in Yangtze River Delta. *Open Journal of Business and Management, 10,* 1245-1273. https://doi.org/10.4236/ojbm.2022.103068

Li, F., & Huang, T. (2020). Analysis on Technical Efficiency and Influencing Factors of Water Supply Industry in China: A Study Based on SFA Measurement of 256 Cities. *Urban Problems, No. 5,* 4-10. (In Chinese)

Li, S., & Gao, Y. (2014). The Selection of Input-Output Indicators in the Empirical Study of Bank Efficiency. *Research of Quantitative and Technical Economics, No. 4,* 130-144. (In Chinese)

Liu, W. (2016). Measurement of Scale Economy and Scope Economy of Chinese Listed Water Enterprises. *Statistics and Decision Making, No. 2,* 176-179. (In Chinese)

Luo, D. (2012). A Note on Estimating the Inefficiency of Three-Stage DEA Model Management. *Statistical Research, No. 4,* 104-107. (In Chinese)

Luo, Z., Zhu, L., Chang, F., Fan, Y., & Zhang, J. (2020). Temporal and Spatial Differences of Urban Water Supply Efficiency and Its Variation Characteristics in China. *Research of Soil and Water Conservation, No. 2,* 307-314+322. (In Chinese)

Lv, F., & Zhong, D. (2013). Development Status and Trend of China's Water Industry. *China Water Supply and Drainage, No. 10,* 12-16. (In Chinese)

Shi, Y., Qian, Z., & Cheng, G. (2012). The Impact of Indicator Selection on Hospital Efficiency Evaluation: A Case Study of Provincial Data DEA Model in 2010. *Chinese Health Policy Research, No. 3,* 67-72. (In Chinese)

Sun, C., Su, L., & Xu, B. (2016). Business Performance Evaluation of Chinese Urban Water Enterprises Based on DEA Model. *Operations Research and Management, No. 3,* 204-210. (In Chinese)

Sun, Z., Bian, C., Chu, Z., & Wang, H. (2021). A Simulation Study on the Evolution of Carbon Emission Regulation and Enterprise Low-Carbon Technology Innovation from the Perspective of Government Regulation. *Industrial Technical Economics, No. 12,* 103-112. (In Chinese)

Tskhai, A. (2022). The Impact of Increasing Environmental Requirements on the Efficiency of Water Utilities: Russian Case. *Clean Technologies and Environmental Policy, 24,* 633-644. https://doi.org/10.1007/s10098-021-02133-9

Wang, Y., & Meng, W. (2004). Evolutionary Game Analysis of Cooperative Competition Mechanism of Supply Chain Enterprises. *Journal of Management Engineering, No. 2,* 96-98. (In Chinese)

Xiao, R, Qian, Li., & Chen, Z. (2012). Research on the Innovation Efficiency of China's High-Tech Industry and Its Influencing Factors. *Management Science, No. 5,* 85-98. (In Chinese)

Xie, Z. (2001). Evolutionary Game Theory under Bounded Rationality. *Journal of Shanghai University of Finance and Economics, No. 5,* 3-9. (In Chinese)

Zhao, C., Deng, J., Zhang, C., & Zhang, Z. (2021). Research on the Shift of the Center of Gravity and Driving Effect of Domestic Water Consumption in the Yangtze River Economic Belt. *Resources and Environment in the Yangtze Basin, No. 4,* 827-838. (In Chinese)

Zhao, X.-G., & Wei, Z. (2019). The Technical Efficiency of China's Wind Power List Enterprises: An Estimation Based on DEA Method and Micro-Data. *Renewable Energy, 133,* 470-479. https://doi.org/10.1016/j.renene.2018.10.049