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Research on China's Aquaculture Efficiency Evaluation and Influencing Factors with Undesirable Outputs

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Abstract Taking the aquaculture area, the number of farming boats and that of aquaculturist as input variables, the aquaculture production as desirable output variable and polluted economic loss as undesirable output variable, this paper conducts SBM model to evaluate the aquaculture efficiency based on the data of 16 aquaculture-developed provinces in China from 2004 to 2011. The results show the efficiency in China has not changed much in recent years with the efficiency values mainly between 0.39 and 0.53, and the efficiency of marine-aquaculture-dominated provinces is generally higher than that of freshwater-aquaculture-dominated ones. To analyze the difference under the efficiency, the panel Tobit model is used with education level factor, training factor, technology extension factor, technical level factor, scale factor and species factor as the efficiency influencing factors. The results show that technology extension factor and technical level factor have significant positive influence.

Key words China's aquaculture industry; efficiency evaluation; influencing factors; SBM model; panel Tobit model

1 Introduction

The food security is critical to China with a population of 1.37 billion. The traditional agriculture development is constrained with the shortage of land resources, so that the aquaculture industry as an important source of food supply should take major responsibility. Continuously improving its efficiency is very important (*MUIR*, 2005). The aquaculture produces not only aquatic products and other desirable output but also polluted economic loss and other undesirable outputs. Therefore, it is necessary to comprehensively consider both the undesirable output and the desirable output for aquaculture efficiency evaluation. In recent years, the rapid development of Chinese aquaculture industry has brought serious environment pollutions. Therefore, it is very important to evaluate the aquaculture efficiency in China with undesirable outputs and analyze the key influencing factors, so as to promote its efficiency.

In recent years, scholars at home and abroad have done lots of researches on the efficiency evaluation in different fields while researches on aquaculture efficiency evaluation are relatively rare. Cinemre *et al*. (2006) studied the cost efficiency of trout breeding in Turkey's black sea coast with DEA-Tobit model, and analyzed its key influencing factors; Asche *et al*. (2009) studied the relationship between the economic efficiency and environmental influencing factors of Norwegian salmon aquaculture, and found out that the cost efficiency was positively related with aquaculturists' experience and education level while negatively related with capital intensity and the scale of the aquaculture. Vassdal and Holst (2011) measured the total factor productivity efficiency of Norwegian salmon farming in 2001–2008 based on DEA- Malmquist method. Taking Denmark freshwater aquaculture as the object and using data envelopment analysis method, Nielsen (2011) analyzed the impact of differences in water purification system and farming scale factor on technical efficiency, showing that the difference of water purification system had no significant influence on the technical efficiency while the farming scale had positive one. Miao *et al*. (2003) studied the technical efficiency of cyprinidae fishes farming in 283 fish ponds of seven provinces in China from 1999 to 2000, and found out that the technical efficiency distributed between 0.51 and 0.98 with the average of 0.708 and that the technical efficiency would increase accordingly with the increase of pond area. Lin *et al*. (2007) studied the technical efficiency of Maoming's fishery from 1994 to 2004 and found that its overall technical efficiency stayed at a high level, which contributed to its aquaculture production in recent years. Using trans-log production function model, Sun (2012) studied the efficiency of China's mariculture and finally proved that the efficiency was at a low level. Wang (2013) studied the efficiency of China's aquaculture industry from 1990 to 2009 with data envelopment analysis and recognized influencing factors on the total factor productivity with the method of multivariate linear regression

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analysis, finding that its total factor productivity was declining during the study period, which was then positively related with fishery technology promotion funding input and the number of trained fishermen and researchers.

To sum up, scholars at home and abroad have not done enough researches on the aquaculture efficiency, often ignoring the aquaculture pollution problems and leading to one-sided efficiency evaluations. With aquaculture pollution as an undesirable output, this paper evaluates the aquaculture efficiency from 2004 to 2011 in China and analyzes the key influencing factors on aquaculture efficiency with the panel Tobit model.

2 Research Methods and Models

2.1 Efficiency Evaluation Model – SBM Model

CCR model, the first model of DEA, is put forward by Charnes, Cooper and Rhodes (1978). Banker, Charnes and Cooper (1984) extend on it and come up with BCC model to deal with the ration of multiple inputs and outputs to gauge the relative efficeceny of Decision Making Unit. Later, DEA is continuously developed and improved to different models. This paper applies the SBM model put forward by Tone (2004) with undesirable output to evaluate the aquaculture industry efficiency in China.

The expression of SBM (slacks-based measure) model is as follows: If we study the efficiency of aquaculture in n provinces, standing for n decision making units of the SBM model, there are three input and output vectors in each decision making unit: resource input, desirable output and undesirable output, represented as $x \in R^m$, $y^g \in R^{s_1}$, $y^b \in R^{s_2}$. The matrix can be defined as follows:

$$X = [x_1, \cdots, x_n] \in R^{m \times n},$$

$$Y^g = [y_1^g, \cdots, y_n^g] \in R^{s_1 \times n},$$

$$Y^b = [y_1^b, \cdots, y_n^b] \in R^{s_2 \times n},$$

where $X > 0,\ Y^g > 0,\ Y^b > 0$, production possibility set P under constant returns to scale is:

$$P = \left\{ \begin{matrix} (x, y^g, y^b) \mid x \ge X\lambda, y^g \le Y^g\lambda, \\ y^b \ge Y^b\lambda, \lambda \ge 0 \end{matrix} \right\},$$

The SBM model of China's aquaculture efficiency evaluation with undesirable output is as follows:

$$E = \min \rho^* = \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{n_1 + n_2}\left[\sum_{r=1}^{n_1} \frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{n_2} \frac{s_r^b}{y_{r0}^b}\right]},$$

$$\begin{aligned} s.t.\quad & x_0 = X\lambda + s^- \\ & y_0^g = Y^g\lambda - s^g \\ & y_0^b = Y^b\lambda + s^b \\ & s^- \ge 0, s^g \ge 0, s^b \ge 0, \lambda \ge 0. \end{aligned},$$

Where E is the aquaculture efficiency; ρ^* is the objective function; s is the slack variable of various resources input, desirable and undesirable output; λ is the weight vector; ρ^* is strictly decreasing with s^-, s^g and s^b, and $0 \le \rho^* \le 1$. When $\rho^* = 1$, namely $s^- = 0,\ s^g = 0,\ s^b = 0$, the evaluated decision making unit is efficient, that is DEA effective. $\rho^* < 1$ means not only the evaluated decision making unit is null and void but also there are too much input or insufficient output, necessarily to be improved.

2.2 Efficiency Influencing Factors Model–Tobit Model

The efficiency value in this paper is between 0 and 1. If this paper analyzes the factors affecting aquaculture efficiency with traditional ordinary least square method, the estimated parameters are biased. The panel Tobit model used here, estimated by the maximum likelihood estimation method, can solve above problems. The Tobit model can be expressed as:

$$\begin{aligned} & E_i' = a_0 + \sum_{j=1}^{k} a_j x_{ji} + \varepsilon_i \\ & E_i = E_i' \quad if\ 0 < E_i' \le 1 \\ & E_i = 0 \quad if\ E_i' < 0 \\ & E_i = 1 \quad if\ E_i' > 1 \end{aligned},$$

where E_i' is the latent variable; E_i is the observed actual dependent variable, namely the efficiency vector in the model; x_{ij} is the independent variable; a_j is the correlation coefficient vector; a_0 is the constant term; ε_i is independent and $\varepsilon_i \sim N(0, \sigma^2)$.

3 Empirical Research

3.1 Sample Selection and Data Sources

This paper selects 16 aquaculture-developed provinces in China as the sample, including Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Sichuan, Jiangsu, Guangdong, Guangxi, Hainan, Shandong, Fujian, Zhejiang, Liaoning and Hebei. The proportion of freshwater aquaculture of the first eight provinces is higher while the mariculture proportion of the latter eight ones is higher. All the data of 2004–2011 are from *Chinese Fishery Statistical Yearbook* (2005–2012).

3.2 China's Aquaculture Efficiency Evaluation with Undesirable Outputs

3.2.1 Variable selection

For characteristics of the aquaculture, this paper takes the aquaculture area, the number of farming boats and that of aquaculturists as input variables, the aquaculture production as the desirable output variable and polluted economic loss as undesirable output variable. Descriptive statistic results of the data are shown in Table 1.

Table 1 Descriptive statistic results

	Input			Desirable output	Undesirable output
Statistics	Aquaculture area (Hectare)	The number of farming boat (kilowatt)	The number of aquaculturist (person)	Aquaculture production (ten thousand tons)	Polluted economic loss (ten thousand yuan)
Maximum	961167	726420	760802	5970419	329363
Minimum	27450	0	46467	303769	0
Mean	399617	10079	273665	2073211	9202
Standard deviation	222007	141612	173869	1475235	29365

3.2.2 Efficiency evaluation

The calculated efficiency values of above provinces with SBM model are shown in Table 2, and the average efficiency values are shown in Fig.1.

Table 2 proves that among the aquaculture-developed provinces in China, the average efficiency of Fujian during 2004–2011 is the highest. The efficiency values in 2004–2005, 2007 and 2011 are all 1 and on the effective frontier. Guangdong also has high aquaculture efficiency with three years of aquaculture efficiencies effective. The aquaculture efficiency of Henan is the lowest, with the average 0.142 and the maximum 0.183, well below the minimum of Fujian.

From Fig.1, we can see that the overall efficiency of aquaculture doesn't change much in China from 2004 to 2011, with the efficiency values mainly between 0.39 and 0.53. The efficiency value of marine-aquaculture-dominated provinces is higher than that of freshwater-aquaculture-dominated ones. With increasing desirable output, the average efficiency of marine-aquaculture-dominated provinces reached the highest in 2007, with the efficiency value of 0.629. Subsequently, the efficiency declined and touched the bottom in 2009 with the efficiency value of 0.500 for the increasing undesirable output. After 2009, the rising of desirable output promoted the mariculture efficiency. The average efficiency of freshwater-aquaculture-dominated provinces is divided by the year 2007. Their average efficiency values before 2007 are significantly higher than those after 2007 with the increasing input. It reached the highest in 2005 with the value of 0.456, and the lowest in 2011 with the value of 0.262.

Table 2 Efficiency evaluation of the 16 provinces in China with SBM model

		2004	2005	2006	2007	2008	2009	2010	2011	Average	Rank
Marine-aquaculture-dominated	Guangdong	0.476	0.936	1.000	1.000	0.891	0.923	0.974	1.000	0.900	2
	Guangxi	1.000	1.000	0.620	0.618	0.532	0.600	0.824	0.905	0.762	3
	Hainan	1.000	0.234	0.892	1.000	0.556	0.518	0.517	0.587	0.663	4
	Shandong	0.572	0.529	0.386	0.424	0.399	0.410	0.391	0.438	0.444	7
	Fujian	1.000	1.000	0.807	1.000	0.895	0.894	0.924	1.000	0.940	1
	Zhejiang	0.318	0.320	0.326	0.443	0.298	0.286	0.313	0.335	0.330	11
	Liaoning	0.348	0.347	0.349	0.346	0.280	0.219	0.210	0.229	0.291	12
	Hebei	0.241	0.220	0.184	0.205	0.147	0.151	0.171	0.166	0.186	15
Average		0.619	0.573	0.571	0.629	0.500	0.500	0.540	0.582		
Freshwater-aquaculture-dominated	Heilongjiang	1.000	0.994	1.000	0.179	0.088	0.085	0.077	0.077	0.437	8
	Anhui	0.259	0.264	0.213	0.237	0.233	0.245	0.254	0.259	0.246	13
	Jiangxi	0.439	0.496	0.341	0.288	0.291	0.271	0.279	0.292	0.337	10
	Henan	0.145	0.101	0.127	0.183	0.137	0.124	0.157	0.165	0.142	16
	Hubei	0.364	0.384	0.434	0.386	0.350	0.310	0.327	0.333	0.361	9
	Hunan	0.458	0.477	0.463	0.517	0.520	0.547	0.572	0.285	0.480	6
	Sichuan	0.649	0.717	0.522	0.468	0.442	0.451	0.452	0.439	0.517	5
	Jiangsu	0.208	0.217	0.228	0.266	0.274	0.237	0.245	0.248	0.240	14
Average		0.440	0.456	0.416	0.315	0.292	0.284	0.295	0.262		

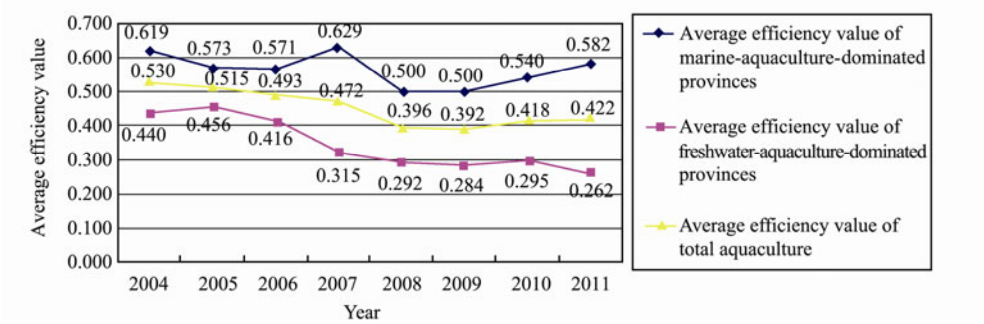

Fig.1 The average efficiency values of 16 provinces in China from 2004 to 2011.

3.3 Influencing Factors Analysis

3.3.1 Variable selection of influencing factors

Referring to the researches by Wang (2013) and the realities in China, this paper mainly selects education level factor, training factor, technology extension factor, technical level factor, scale factor and structure factor to establish the following Tobit model:

$$E_{it} = \alpha_i + \beta_1 EDU_{it} + \beta_2 TRA_{it} + \beta_3 TEC_{it} + \beta_4 IND_{it} + \beta_5 SCA_{it} + \beta_6 SPE_{it} + \mu_{it} ,$$

where E_{it} is the aquaculture efficiency of i province in t year; *EDU* is the education level variable; *TRA* is the training variable; *TEC* is the technology extension variable; *IND* is the technical level variable; *SCA* is the scale variable; *SPE* is the farming species variable.

Education level factor (*EDU*). The education level of aquaculturists directly determines the use of advanced aquaculture technology, which can promote efficiency. The higher the education level, the better the use of advanced aquaculture technology. For the data availability, this paper takes the education level of aquaculture technology popularization personnel as that of aquaculture practitioners.

Training factor (*TRA*). Aquaculturists are direct participants of aquaculture. Their aquaculture knowledge and skills determines the aquaculture development. Advanced knowledge and skills are beneficial to the efficiency. This paper evaluates aquaculturists' training condition by the percentage of fishermen trained by technology promotion agency in total fishermen.

Technology extension factor (*TEC*). The number of aquaculture technology extension agency determines how fast the fishermen accept the advanced technology. The more agencies, the faster the fishermen master advanced technology. This paper measures the technology extension level by the proportion of the region's technology extension agencies in the total agencies in China.

Technical level factor (*IND*). From Chinese aquaculture development in recent years, technology plays a key role in aquaculture production and efficiency (Meng, 2013). The industrial aquaculture represents a kind of advanced farming pattern with high efficiency and technology (Chen *et al*., 2012). The higher the industrial aquaculture proportion in a region, the better the region's aquaculture efficiency. This paper evaluates the technical level of aquaculture in a region by the percentage of industrial aquaculture area in the total one.

Scale factor (*SCA*). On the one hand, large-scale aquaculture could bring economies of scale, and save production cost or increase output to a certain extent; on the other hand, extensive management, drug abusing and lacing technology in Chinese aquaculture have caused serious environment pollutions and the larger the farming scale, the more serious the pollutions (Bao, 2012). The influence of scale factors on the efficiency may be positive or negative, and it depends on which effect plays a greater role. This paper evaluates the scale factor by the aquaculture area.

Farming species factor (*SPE*). The efficiency of different species such as fish, shellfish, algae is different. As the main way of fish farming in China at present, cage-farming depends on artificial feeding and polluting the water with the residual, brings more undesirable output than other species (Hu, 2003). Thus, fish farming may reduce the efficiency. This paper evaluates the farming structure factor by the percentage of fish production in the total aquaculture production.

Table 3 Variable definition

Variable type	Variable name	Symbolic representation	Calculation method
Dependent variable	Aquaculture efficiency	E	SBM
	Educational level factor	EDU	The number of technology promotion personnel with college degree or above of a province / the number of total technology promotion personnel of a province
	Training factor	TRA	The number of trained fishermen of a province/the number of total fishermen of a province
Independent variable	Technology extension factor	TEC	The number of technology extension agency of a province/ the number of total technology extension agency in China
	Technology level factor	IND	Industrial aquaculture area of a province/total aquaculture area of a province
	Scale factor	SCA	Extremum standardization of the aquaculture area in a province
	Farming species factor	SPE	Fish farming production of a province/Aquaculture production of a province

Note: The industrial aquaculture scale is represented by cubic meters of water and the water body height of industrial aquaculture is relatively low. To simplify the technical level factor, this paper supposes that the water body height is 1 meter. The aquaculture area indicator is used in the extremum standardization form, because the order of magnitude of area indicator differs greatly from others.

3.3.2 Tobit model regression and result analysis

Based on the aquaculture efficiency evaluation by SBM model, this paper analyzes influencing factors by panel Tobit model. The Tobit regression results of all influence factors and the efficiency value are shown in Table 4.

Table 4 shows that the maximum likelihood ratio of the regression is −23.8034 and the *P* value is 0.000, illustrating that the regression analysis is meaningful. At the 5% significant level, technology extension factor, technology level factor, scale factor and farming species factor all have significant influence on efficiency. However, the influencing factors like training factor and educational level factor are not significant. The detailed analysis is as follows:

The training factor and educational level factor have insignificant positive impact on the efficiency. Enhancing aquaculturists' educational level and increasing the number of fishermen-technical training agencies may have positive influence on the efficiency.

Technological extension factor has positively significant influence on the efficiency. If the number of technology extension organizations in the province accounts for one more percent of the total number in China, its efficiency will correspondently increase by 0.6804831 percent. As for the technical-factor-dominated aquaculture, increasing the number of technology extension organizations helps more fishermen to have access to advanced aquaculture technology, improving the efficiency.

The technical level factor represented by industrial aquaculture scale has positive significant influence on the efficiency. If the proportion of industrial aquaculture scale increases one percentage, the efficiency will increase by 16.8289 percent with an significant effect. The industrial aquaculture represents a kind of advanced farming pattern with lower pollution, more output and high efficiency. The higher proportion of industrial aquaculture scale, the higher level of technology, and more efficient the aquaculture is.

Scale factor has significant negative influence on the efficiency. If the farming area accounts for one more percent in the country, the efficiency value will fall by 0.5273547 percent. This result shows that in the current aquaculture, the negative influence of scale factor plays a main role for the efficiency of breeding. The result is consistent with Asch's research in 2009.

Farming species factor represented by the proportion of fish farming has significant negative influence on the efficiency. If the fish farming production accounts for one more percent of the total aquaculture production in a province, its efficiency value will correspondently decrease by 0.4098666 percent. This shows that the efficiency of fish farming is at a low level, a higher proportion of fish farming may cause a decline in efficiency.

Table 4 Tobit regression results

Variable	Coefficient estimates	*Z* value	*P* value
EDU	0.2189112	1.37	0.171
TRA	0.0496564	0.59	0.558
TEC	0.6804831	5.26	0.000†††
IND	16.8289000	2.12	0.034††
SCA	−0.5273547	−4.78	0.000†††
SPE	−0.4098666	−4.45	0.000†††
cons	0.5674333	4.51	0.000†††
Log likelihood	−23.8034	*P* value	0.000†††

Note: †† indicates significance at 5% level, ††† indicates significance at 1% level.

4 Conclusions

This paper analyses the aquaculture efficiency and influence factors of 16 provinces in China from 2004 to 2011. The results show that Chinese aquaculture efficiency has not changed much in recent years, with the efficiency values mainly between 0.39 and 0.53. The aquaculture efficiencies of marine-aquaculture-dominated provinces are generally higher than those of freshwater-aquaculture-dominated ones. Among 16 provinces, the average efficiency of Fujian is the highest and that of Henan province is the lowest. Analyzing influencing factors on the efficiency, this paper concludes that educational level factor, training factor, technology extension factor and technology level factor have positive influence on the efficiency while the last two are significant. Scale factor and farming species factor have negatively significant influence on the efficiency.

In order to improve aquaculture efficiency, China should constantly improve the aquaculturists' education level, increase training efforts for fisherman, improve coverage of technology extension agency, raise the proportion of industrial aquaculture, and enhance regulation of the aquaculture environment especially for fish farming.

However, because of the problem as data collection, shortcomings are inevitable in this paper. For example, some variables or proxies are not very appropriate. We will be about theses problems in the successive research.

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