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The Economies of Scale of Turbot Industrial Running Water Aquaculture System in China: A Case from Shandong Province

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Abstract

China is the most important production contributor of farmed turbot in the world. The economies of scale of turbot farming industry in this significant country haven't been studied in detail. In this study, based on survey data from the largest farming area of this species, Shandong Province of China in 2015, DEA (Data Envelopment Analysis) was used to assess the turbot culture efficiency of different farming scales. All these turbot farmers used industrial running water aquaculture system, which provided over 90% of China's total production of this species. The results showed that (1) the overall efficiencies of different farms increased with the enlargement of their farming scale and (2) the efficiency of each farming scale could still be improved. Given the outputs unchanged, a reduction in inputs can improve the utilization efficiency of feeds, electricity and labor, and reduce the irrational exploitation of land and groundwater resources; this change would not only increase economic benefits but also protect natural resources, thereby achieving the harmonious development of the economy and environment.

Keywords: Turbot; Industrial running water aquaculture system; DEA; Resource; Efficiency

Introduction

China has become the largest production contributor of farmed turbot (*Scophthalmus maximus*) in the world. Turbot aquaculture is mainly distributed in the regions of Liaoning, Tianjin, Hebei, Shandong, Jiangsu and Fujian province, among which Shandong province is the largest area with annual production up to 49 % of the total of turbot. In china, the industrial farming methods of turbot are running water aquaculture. The Yellow Sea and Bohai Sea are the main areas that conduct industrial running water aquaculture of turbot. Underground seawater is the main water source for this aquaculture mode However, this mode has some disadvantages, including (i) ignorance of ecological and environmental protection and low efficiency of the utilization of a variety of resources, e.g. land, water and electricity, and (ii) ignorance of long-term interests and intense disordered intra-industry competition. The small and scattered industrial distribution is not conducive to the standardized management and development of turbot aquaculture.

Current, the methods for efficiency analysis include SFA (Stochastic Frontier Analysis) and DEA. The DEA method is a reliable method for quantitative analysis in studying the efficiency of various industries (Coelli, Prasada Rao, O'Donnell & Battese, 2005; Cook & Seiford, 2009; Ray, 2004; Tone & Tsutsui, 2010; Sun, 2011; Zhang, Zhang & Chen, 2010; Qin, Zhang & Luo, 2011; Wu, Wang & He, 2012). However, the DEA method applied in the fisheries economy is limited (Sharma, Leung, Hailiang & Peterson, 1999; Helfand &Leveine,

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2004; Cinemre, Ceyhan & Bozoglu, 2006; Alam, 2011). Using the DEA-Tobit two stage model, Cinemre Ceyhan & Bozoglu (2006) studied the cost efficiency of trout farms in the Black Sea region and found that the cost efficiency was positively correlated with pond tenure, farm ownership, experience of the operators, education level of the operators and credit availability, while feeding intensity, pond size and capital intensity had negative effects on cost efficiency (Cinemre, Ceyhan & Bozoglu, 2006). The efficiency of marine fisheries in China was evaluated by using DEA theory and found that the efficiencies in Liaoning, Jiangsu, Fujian, Shandong, and Guangdong were the highest (Liang & Yu, 2014). Previous studies revealed that the fishery economy in China still had great space to improve and the fishery technology should be earnestly promoted and applied to improve fisheries management and adjust the fishery scale, thus contributing to TFP (total factor productivity) and enhancing the efficiency of the input factors. When the DEA method was applied to assess the efficiency of fishery production, indicator selection and model construction are mostly focused by researchers.

Shandong is the largest province of turbot aquaculture in China, and industrial running water aquaculture is the main turbot aquaculture mode in this province. In 2015, we conducted a large-scale sampling survey for turbot running water aquaculture in Rizhao, Huangdao, Laizhou, Yantai, and Weihai city in Shandong province. In this study, the optimal approach includes scale efficiency, technical efficiency and overall efficiency for turbot industrial running water aquaculture was investigated using DEA method to achieve the coordinated development of turbot aquaculture in economy, resources and the environment. Our results revealed that a comprehensive evaluation of the economic efficiency and ecological efficiency of such aquaculture is needed and will contribute to sustainable development of turbot aquaculture. Also, our results provided the basis for application of DEA method in aquaculture-related economic research.

Materials and Methods

Data Collection

The farmer households conducting industrial running water aquaculture of turbot in Rizhao, Huangdao, Laizhou, Yantai, and Weihai city in Shandong province was surveyed using random sampling method in 2015. A total of 92 valid samples were collected. The aquaculture scale was divided into five categories: small [0, 1000), small/medium [1000, 2000), medium [2000, 3000) medium/large [3000, 5000), and large [5000, +∞). Totally, 25 of small-scale farmer households, 22 of small/medium-scale farmer households, 16 of medium-scale farmer households, 18 of medium/large-scale farmer households, and 11 of large-scaler farmer households were investigated (Table 1).

DEA method

The efficiency of industrial running water aquaculture of turbot was studied using DEA method. The mathematical programming was:

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$$
\begin{aligned}
&\min \theta \\
s.t.\ &\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{ik} \\
&\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rk} \\
&\sum_{j-1}^{n} \lambda_j = 1 \\
&\lambda \ge 0 \\
&i = 1,2,3....,m; r = 1,2,3...,q; j = 1,2,3...,n
\end{aligned}
$$

Dual programming:

$$
\begin{aligned}
&\max \sum_{r=1}^{q} \mu_r y_{rk} - \mu_0 \\
s.t.\ &\sum_{r=1}^{q} \mu_r y_{rj} - \sum_{i=1}^{m} \nu_i x_{ij} - \mu_0 \le 0 \\
&\sum_{i=1}^{m} \nu_i x_{ik} = 1 \\
&\nu \ge 0; \mu \ge 0; \mu_0\ free \\
&i = 1,2,3...,m; r = 1,2,3...,q; j = 1,2,3...,n
\end{aligned}
$$

Wherein, the y_i refers to the output variable, x_i refers to the input variable, and θ is the value of the resulting efficiency. The BCC (Banker__Charnes__Cooper) model is a DEA model in VRS (Variable Returns to Scale) radial, with multiple inputs/single output or multiple inputs/multiple outputs. Relaxation problems may occur in the VRS model.

Economic meaning of the parameters

(1) DEA efficiency analysis

When θ = 1 and s- = s+ = 0, the DMU is called strongly DEA effective. In this case, the DMU (Decision Making Unit) is both scale effective and technically effective, indicating that the production factors of the DMU has reached the optimal combination and obtained the optimal output.

When θ = 1 and s- ≠ 0 or s+ ≠ 0, the DMU is called weakly DEA effective. In this case, the DMU is either scale ineffective or technically ineffective. For the DMU, the input x can be reduced s- while the original output y remains unchanged, or the output can be increased by s+ with a constant input x.

When θ < 1, the DMU is called non-DEA effective. In this case, the DMU is both scale ineffective and technically ineffective. In the economic system consisting of the DMU, the original output y can remain unchanged by reducing the input to be the θ ratio of the original input x.

(2) DMU projection analysis

The projection analysis of DMU in the production frontier showed the non-DEA effective DMU is DEA effective in the projection of the production frontier. Therefore, when the DMU j is non-DEA effective, there must exist two cases: input redundancy and output insufficiency. Each non-zero component in the variable s- is the amount of redundancy corresponding to the input x, and each non-zero component in the variable s+ is the amount of insufficiency corresponding to the output y. By adjusting the values of the input and output indicators for a non-DEA effective DMU j, the DMU can be converted to be DEA effective.

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Model Selection

There are four basic models of DEA method. The selection of model in this study was based on following principles:

(1) The level of the operating performance in this analysis was evaluated using the efficiency values including overall technical efficiency, pure technical efficiency, and scale efficiency. Because the application of C^2GS^2 is limited only when the overall technology is effective, the C^2GS^2 model was not selected in this study. The number of input and output indicators selected in this study was small, with no special restrictions and conditions required for the relative importance of the input and output indicators in the performance evaluation, and thus, the C^2WH model was excluded. The CCR requires a constant return to the scale, while the BCC model can fully apply the efficiency values of overall technical efficiency, pure technical efficiency, and scale efficiency to analyze the operating performance of a DMU on the basis of the changeable returns to the scale; consequently, the BCC model was selected as the computation model in this study (Table 2).

(2) The basic DEA model can be divided into input-oriented type and output-oriented type. The input-oriented type requires that the output is limited with certain conditions, and minimal input is pursued with the best effort; the output-oriented type is to pursue the maximal output based on the same input. The input-oriented DEA model was selected in this study, aiming to reduce the input and decrease the cost on the basis of the constant current aquaculture output, thereby improving the economic efficiency and promoting the rational development and utilization of resources.

Indicator Selection

The method for evaluation of cost of industrial running water aquaculture of turbot was referred to the method of Huang & Yang (2011) and results were listed in Table 3. A total of 6 input indicators and 1 output indicator were investigated in this study (Table 4). Clearly, the expenditures of electricity, feed and labor accounted for a large portion of the total cost. In addition, with rapid economic development the land resources are increasingly scarce, and water resources have always been a bottleneck for aquaculture development. Thus, this study aimed to explore the rational development and utilization of resources from the perspective of resource inputs and to improve the efficiency of aquaculture.

Results

In this study, the aquaculture efficiency of the farming households conducting running water aquaculture of turbot in different aquaculture scales were studied using DEAP 2.1 software. The results were shown in Table 5.

The results showed that the aquaculture efficiencies of different aquaculture scales were different with a tendency of the larger the scale, the higher the efficiency. For the overall efficiency, the small scale and the small/medium scale values were similar with low efficiency which had much room for improvement. The medium scale and the medium/large scale values were similar with a greatly improved overall efficiency. The large-scale farmer households had the highest overall efficiency. The pure technical efficiency increased with the scale in an ascending order. The scale efficiencies were all high, with little difference among different scales and in the same order as the overall efficiency.

The small-scale farmer households included 1 strongly effective DMU, accounting for 4.00% of the total, 7

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weakly effective DMUs accounting for 28.00% of the total and 17 non-effective DMUs accounting for 68.00% of the total. The small/medium-scale farmer households included 4 strongly effective DMUs accounting for 9.10% of the total, 8 weakly effective DMUs accounting for 36.36% of the total and 10 non-effective DMUs accounting for 45.45% of the total. The medium-scale farmer households included 7 strongly effective DMUs accounting for 43.75% of the total; 4 weakly effective DMUs accounting for 25.00% of the total and 5 non-effective DMUs accounting for 31.25% of the total. The medium/large-scale farmer households included 7 strongly effective DMUs accounting for 38.89% of the total, 8 weakly effective DMUs accounting for 44.44% of the total and 3 non-effective DMUs, accounting for 16.67% of the total. The large-scale farmer households included 6 strongly effective DMUs, accounting for 54.55% of the total, 4 weakly effective DMUs accounting for 36.36% of the total and 1 non-effective DMU accounting for 9.10% of the total. Clearly, with the expansion of the scale of farmer households, the effectiveness of the DMUs was gradually increased, the utilization of resources was improved, and the maximization of output was further guaranteed on the basis of the minimal inputs. For large-scale aquaculture, no improvement is required in labor, feed, and the amount of fry, and a minor reduction is required only in electricity, farming area, and fixed assets.

For the slack variables, except for large-scale aquaculture, the farming area of all other scales was excessive. Therefore, the farming area can be appropriately reduced to fully use the water body and enhance the farming yield. With the exception of large-scale aquaculture, the feed input for all other scales was excessive. Feed is an important component of the cost of aquaculture. The control of feed costs can effectively reduce the cost and improve the economic efficiency. The use of electricity for aquaculture in all scales was excessive. The amount of water cycling can be adjusted to control the consumption of electric power. The fixed assets were not fully utilized, with a large idleness in medium-scale and medium/large-scale aquaculture. The labor input for small/medium-scale and medium-scale aquaculture was slightly excessive. Fry, feed, electricity, and fixed assets are the important components of aquaculture. Controlling the inputs of production factors can reduce the cost and increase the profit margin (Table 6).

The results showed that although maintaining the same production, industrial running water aquaculture of turbot in Shandong Province should appropriately reduce the input of resources to reduce the aquaculture cost and maximize the efficiency. Overall, the farming area can be reduced by 480 m^2, which is an 11.66% decrease based on the current level. The feed can be reduced by 2.72 yuan/kg, which is an 11.80% decrease based on the current level. The electricity can be reduced by 0.53 yuan/kg, which is an 11.50% decrease based on the current level. The labor cost and the depreciation of fixed assets can be reduced by 0.32 yuan/kg and 0.36 yuan/kg, which are 12.50% and 12.90% decreases, respectively, based on the current levels. Thus, there is much room for improvement for the current industrial running water aquaculture of turbot in Shandong Province, with a particular emphasis on resource conservation. The data showed a lower resource utilization rate. The resources of land, electricity, feed, and labor can be reduced by approximately 10%, based on the current levels. The fixed assets were not fully utilized. The effective farming density per unit is 26/m^2, which is 41.30% higher than the survey result of 18.4/m^2.

Discussion

In this study, the optimal approach including scale efficiency, technical efficiency and overall efficiency for turbot industrial running water aquaculture was investigated using DEA method. The production of different

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scales affected by farming area, amount of fry, feed, electricity bill, employee salary and annual depreciation of fixed assets were studied. Our results revealed that the expenditures of electricity, feed and labor made up a large portion of the total cost. These results were in accordance with study of Iliyasu, Mohamed, Ismail, Amin & Mazuki (2016), finding that 4 inputs indicators (stocking density, feed, labour and other relevant production costs) had positive sings and statistically significant impacts on the production of cage fish. Clearly, feed and electricity are the major components of aquaculture cost. The sensitivity analysis for the impact of the uncertain factors on the production showed that the sensitivity coefficients of feed and electricity were -3.51 and -1.18, respectively, indicating that an increase of 1% in the cost of feed resulted in the decrease of 3.51% in the production and that an increase of 1 % in the cost of electricity resulted in the decrease of 1.18% in the production (Iliyasu, Mohamed, Ismail, Amin & Mazuki, 2016).

We also found that the larger aquaculture scale had higher efficiency. The efficiency may give an index to the profit of farmer. The higher the efficiency, the higher the profit was. These results were in accordance with previous studies. Huang & Yang (2011) found that the small scale of turbot had net profit of 1.15 Yuan/kg, the medium scale of turbot had net profit of 13.64 Yuan/kg, and the large scale of turbot had net profit of 21.88 Yuan/kg (Huang & Yang, 2011). The reason for this tendency might be that more aquaculture management was put into large scale.

DEA is a non-parametric estimation method. Previous studies had revealed that DEA could be applied for analysis of aquaculture efficiency. Zheng & Zhou (2002) applied DEA theory to the study of marine fisheries in China, concluding that the efficiencies in Liaoning, Jiangsu, Fujian, Shandong, and Guangdong were the highest, while other provinces and cities had a room for improvement. Liang & Yu (2014) used panel regression and DEA for the overall analysis and evaluation of the economic input-output performance of fisheries in 27 provinces of China in 1999-2010. Xing, Xu & Lin (2014) applied the two-stage DEA model and Tobit model to evaluate the technical efficiency of aquaculture, and the results showed that the technical efficiency of aquaculture has much room for improvement; to improve the economic efficiency of aquaculture, the government and farming cooperatives should fully employ the organizing functions to strengthen the technical education and training of aquaculture farmers and expand the scope and intensity of agricultural subsidies, thus promoting the development of mechanization in aquaculture. These results revealed that the fishery economy in China still had much room for improvement. Combined our study with previous studies, we were confirmed that DEA was a reasonable choice for analysis of aquaculture efficiency.

Conclusions and Recommendations

1. Large resource consumption has become an important issue for industrial running water aquaculture

The 2014 survey data revealed the following aquaculture problems noted by aquaculture producers: water quality, water amount, land, technology, and diseases. The farmers believed that aquaculture water problems existed, accounting for 100% of the respondents; the main problems included deterioration in water quality, drawdown, and seawater intrusion. With underground marine water as the aquaculture water, the daily running water is 200% for running-water aquaculture. The water consumption for turbot farming was 30 m^3/kg. Due to the disorderly competitive utilization, the current groundwater level had significantly decreased. The water-taking machine was often idling, which not only wasted power resources but also damaged the equipment.

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Some individual farmers lacked awareness of the need for ecological protection of the farming environment. To reduce the cost of aquaculture, the polluted water was discharged directly. Although high-density aquaculture can enhance production, without the supporting purification equipment, the intensive aquaculture can lead to more serious pollution.

2. Economies of scales have not been achieved

Although some farmer households have reached large-scale production, there is still a wide gap from scale economies. Based on the data of the 92 valid survey samples in this study, the largest farming area was 10,000 m^2, and the smallest area was 200 m^2, with an average of 4116 m^2; the farming area of the effective DMU was 4033 m^2. Analysis showed that the current farming area is excessive and can be reduced by 430 m^2 based on the current level; that is, a farming area of 3600 m^2 is appropriate. In economics, the term "economies of scale" is defined as a larger production scale leading to a lower cost. With the increase in production, the unit cost is lowered and the profit is increased. In this study, although the aquaculture scale of the farmer households was large, full use of the resources was not achieved, mainly due to insufficient utilization of the fixed assets.

3. Intensify water conservation

Studies have suggested that the problem can be solved by considering the following four recommendations. First, the aquaculture cycle can be shortened. Currently, running water aquaculture takes approximately 18 months from fry to adult fish (1-1.2 kg/tail). Considering the daily water change is 300%, a tail of commercial fish needs 74 m^3/kg water. If fast-growing fry are used, they can reach the adult stage in 10-12 months, with a water consumption of 41-50 m^3/kg. Second, the farming area can be reduced. The above study suggested that the farming area can be reduced by 480 m^2, with a water consumption of 64 m^3/kg while maintaining the same aquaculture cycle. Third, the aquaculture cycle and farming area can be reduced in the same time, with a water consumption of 35-44 m^3/kg. Finally, on the basis of case three, the amount of daily running water can be reduced, that is, the use of recycled water for aquaculture, with a water consumption of 0.8 m^3/kg. Although the government does not impose a fee for the use of underground marine water, the opportunity cost of the water resource is always present. On one hand, it is reflected as the scarcity of the water resource, drawdown, low pumping efficiency, and increased electric power consumption; On the other hand, the cost of well digging is 100 yuan/m, while the cost of digging a deep well is higher than that of a shallow well. Studies have suggested that this digging cost should be included in the opportunity cost of water resources. According to the performance evaluation of economic value added (EVA), the revenue of a business should be considered as the offset of the income and all capital costs, including the opportunity cost of its own funds.

4. Try hard to reduce the input of the dominant costs

Using a farming area of 1,500 m^2 as an example, the monthly electricity consumption was 5000 degrees. The electricity consumption was mainly used for extracting underground marine water. Studies have suggested that, on one hand, electricity consumption can be reduced by reducing the farming area, thus lowering water consumption; on the other hand, after strengthening management, irrational consumption can be reduced. The above analysis showed that after reducing the input by 13.1% with unchanged output based on the current input level, the calculated electricity consumption for the original farming area of 1500 m^2 can be 3828 degrees. In addition, the costs of feed and labor can be reduced by 18.8% and 13.7%, respectively, with an unchanged output after strengthening management.

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5. Make full use of land resources

Currently, the land rental costs account for 0.42% of the total cost. However, from the perspective of long-term development, land supply is limited. In economics, with the same supply, the land prices will increase with increasing demand. Currently, the density of running water aquaculture of turbot is lower than that of recirculating aquaculture, showing the failure to take the full advantage of the limited land resources.

In conclusion, the overall efficiency of the current industrial running water aquaculture of turbot in Shandong Province is not high. Management should be strengthened to keep the output unchanged while reducing the input, thereby reducing costs while improving the efficiency of resource use.

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Table 1. Descriptive statistics

Variable	*N*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*	*N*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Production	25	0.63	0.10	0.10	2.55	22	4.39	4.31	0.42	19.95
Area	25	548.00	30.80	200.00	800.00	22	1388.60	249.70	1000.00	1700.00
Survival rate	25	80.80	1.34	65.00	90.00	22	77.95	9.84	50.00	95.00
Feed	25	7.81	0.40	1.70	10.80	22	41.87	27.76	6.00	107.10
Electricity	25	5.74	0.30	3.00	9.60	22	8.18	4.78	1.00	24.00
Labor	25	0.01	0.01	0.00	0.01	22	3.44	3.13	0.00	12.00
Depreciation	25	3.90	0.24	1.11	6.09	22	6.20	4.37	1.10	22.40
Production	16	5.66	2.73	1.04	11.90	18	8.79	5.05	3.92	25.92
Area	16	2133.80	257.90	2000.00	2940.00	18	3567.00	530.00	3000.00	4600.00
Survival rate	16	78.38	11.26	50.00	99.00	18	83.17	6.72	70.00	95.00
Feed	16	68.57	32.49	25.00	120.00	18	90.93	41.98	39.15	180.00
Electricity	16	11.16	5.48	6.00	27.60	18	18.46	8.24	8.00	36.00
Labor	16	0.87	3.47	0.00	13.20	18	10.24	4.54	4.50	20.00
Depreciation	16	1.12	4.48	1.30	19.40	18	9.86	6.98	0.00	25.55
Production	11	15.82	7.31	3.92	25.92					
Area	11	6970.00	1913.00	3000.00	4600.00					
Survival rate	11	86.36	8.39	70.00	95.00					
Feed	11	183.00	96.30	39.15	180.00					
Electricity	11	38.00	8.24	8.00	36.00					
Labor	11	21.67	4.54	4.50	20.00					
Depreciation	11	21.04	6.98	0.00	25.55					

Table 2. Characteristics of the four basic models of DEA

Computation model	Differences
C^2GS^2	Applicable only when the overall technology is effective
C^2WH	The relative importance of the input and output indicators is restricted, with a requirement in the number of indicators.

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CCR	The return to scale is fixed; the resultant value of overall technical efficiency is the product of the scale efficiency and the technical efficiency.
BCC	Under the premise that the return to the scale is changeable, the overall technical efficiency, pure technical efficiency, and scale efficiency can be analyzed simultaneously.

Table 3. Composition of the accounting cost of industrial running water aquaculture in 2015

Items	Amount (Yuan/kg)	Proportion in each cost (%)	Proportion in the total cost (%)
Expenditure on fry	2.60	8.27	6.87
Expenditure on fishery drugs	0.37	1.18	0.98
Expenditure on feed	23.07	73.58	61.05
Expenditure on coal	0.00	0.00	0.00
Expenditure on electricity	4.62	14.54	12.07
Wage of the temporary labor	0.76	2.42	2.01
Variable cost	31.42	100.00	82.97
Rent of land	0.15	2.33	0.40
Employee (long-term labor) salary	2.57	39.22	6.68
Equipment maintenance cost	1.00	15.50	2.64
Depreciation of fixed assets	2.80	42.95	7.31
Fixed cost	6.52	100.00	17.03
Total cost	37.94		100.00

Table 4. Results of indicator selection

Input indicator	Output indicator
Farming area (m^2)	
Amount of fry (10,000 tails)	
Feed (10,000 yuan)	Production (5000 kg)
Electricity bill (10,000 yuan)	
Employee salary (10,000 yuan)	
Annual depreciation of fixed assets (10,000 yuan)	

Table 5. Results of the efficiency evaluation for different aquaculture scales

Scale	Overall efficiency	Pure technical efficiency	Scale efficiency
Small	0.467	0.659	0.715
Small/medium	0.530	0.768	0.719
Medium	0.822	0.901	0.898
Medium/large	0.806	0.943	0.859
Large	0.889	0.991	0.899

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Table 6. Data of the slack variables for different aquaculture scales

Scale	Amount of fry	Farming area	Feed	Electricity	Fixed assets	Labor
Small	5.507	25.116	0.562	0.055	0.233	0.000
Small/medium	0.601	67.340	0.997	0.696	0.400	0.667
Medium	2.501	12.406	4.408	0.561	1.094	0.050
Medium/large	0.000	61.516	0.900	1.259	1.409	0.000
Large	0.936	0.000	0.000	0.460	0.456	0.000