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Analysis on technical efficiency and influencing factors of fishing vessels: a case study of Haizhou Bay, China

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Abstract

This paper used Data Envelopment Analysis (DEA) to measure the technical efficiency of fishing vessels in Haizhou Bay, and then used the Tobit regression to define its influencing factors. This study shows that the overall fishing capacity utilization of fishing vessels at present is very low which indicates that there is a serious problem of waste of resources in Haizhou Bay. Specifically, the engine power, hull length, vessel age and annual days of fishing at sea are negatively correlated with the fishing vessels technical efficiency which means the decrease of the engine power, hull length, vessel age and annual days of fishing at sea will increase the fishing vessels technical efficiency. Moreover the captain's working seniority, fuel subsidies and total annual costs are positively correlated with the fishing vessels technical efficiency which means the decrease of working seniority, fuel subsidies and total annual cost will decrease the fishing vessels technical efficiency. However, only the *p* value of annual days of fishing at sea (p=0.007) and total annual costs (p=0.001) are significant at 5% significance level. Therefore, it may be concluded that annual days of fishing at sea and the total annual costs are the main impacting factors.

Keywords: Technical efficiency, Influencing factors, Haizhou Bay, DEA, Tobit regression

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Introduction

Decline of fisheries resources has received significant attention from all the stakeholder nations of coastal fisheries, and their relevant national as well as international organizations globally. Strengthening the management of marine fishing capacity, carrying out responsible fishing and promoting the economic development of marine fishing industry are inevitable requirements for the sustainable development for marine fisheries as well as for the important task for fisheries management in the present or even quite a long time in the future (Zheng *et al*., 2009). The marine fishing industry is an important component of China's marine fisheries which has developed and made remarkable achievements since the founding of New China. According to the data [1] from the National Marine Information Center of China, the marine fishing output production was 3.145 million tons in 1978, and 10.268 million tons, which is first time it exceeded 10 million tons, in 1995, and 13.996 million tons in 2013. However, the marine fisheries resources are not inexhaustible. From the beginning of the 1990s, China's coastal areas have received much emphasis on the development of the marine fishing industry, such as blind increase in fishing vessels and nets. Therefore, uncontrolled fishing has made China's marine fishing intensity to far exceed the regenerative capacity of fisheries resources which leads to a severe recession of China's offshore fisheries resources and an increasingly clear phenomenon of fisheries resources scarcity (Chaoqing, 2007; Yuke, 2009; Handuo, 2013). As a result, all of these would seriously threaten the sustainable development of China's marine fisheries resources.

With the reform of the economic management system and the improvement of the socialist market economic system in China, the effective decision-makings have been regarded as the core of how to enhance the economic efficiency and become a subject of great importance which is in urgent need to be addressed for the economic management and investment in construction projects in China. In economics, efficiency refers to the best interests of the community benefitting from scarce resources (ManKiw, 2013). In other words, the efficiency in economics is putting the scarcity of resources as the premise which means the maximum degree of utilization of social resources under the condition of certain technical levels or investments (Jiao, 2013). Because the social resources are scarce, the management of these resources is particularly important (ManKiw, 2013). Fisheries resources as one kind of social resources, has all characteristics of the latter. In the fisheries economics and management, all kinds of activities require decisions, such as how to increase production, improve product quality, improve labor productivity, reduce capital occupation, save cost expenses, increase profitability

[1] http://wdc-d.coi.gov.cn/nmdis/

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(Zhaoqun, 2015). Therefore, there must be a scientific theoretical basis and methods should be practiced to help make the decisions which contain no or less mistakes (Shen, 2014). Fisheries technical efficiency is an important indicator to evaluate the quality of the fisheries economy growth, which refers to the ability to obtain the maximum output from a certain combination of input elements or the ability to use minimum input elements under certain combinations of output elements. Hence, how to improve the technical efficiency of fishing vessels and realize the rational allocation of fisheries resources will occupy an important position in fisheries academia for a long time. Especially for a country like China which has a severe recession of offshore fisheries resources with low degree of fisheries resources utilization, low efficiency and low benefit, the research of this issue is becoming more important (Yuan, 2014).

The study of fisheries technical efficiency began in 1983, Hannesson (1983) estimated fisheries technical efficiency by using the hypothetical single input-output function, and he pointed out that the level of technical efficiency can significantly affect the economic benefit and economic growth of fisheries (Belbase and Grabowski, 1985; Fare *et al*., 1994; Fabio, 2009) as well as enhance industrial competitiveness (Porter, 1980; Odeck, 2000; Los and Timmer, 2005); Coelli (1995) further proposed that the use of the DEA-Tobit model can not only assess the level of technical efficiency, but also define the main factors affecting technical efficiency. Fousekis, P. and Klonaris, S. (2003) assessed the technical efficiency (TE) and its interactions with vessel- and skipper-characteristics for the fleet of trammel netters in Greece. Fabio *et al*. (2009) estimated fishing capacity, technical efficiency, scale efficiency and capacity utilization with a non-parametric approach using a data envelopment analysis (DEA) model in a particular small-scale fishery in the Mediterranean, i.e., the Northwest Sardinian fleet in Italy. Jamnia *et al*. (2015) utilized a Cobb–Douglas stochastic production frontier, including a model for vessel-specific inefficiencies to analyze the technical efficiency of fishery with a sample of 300 fishing vessels including 166 inshore operating vessels and 134 offshore operating vessels in the Chabahar Region, Southern Iran. Various scientific studies were carried out on the efficiency of fishing vessels in China. For example, Shuimei (2005) analyzed the annual changes of five main types of fishing vessels on the basis of fisheries statistical information and related investigation materials of Fujian Province from 1981 to 2003 using the DEA method. Chunlei *et al*. (2007) used the Stochastic Frontier Analysis (SFA) method which was based on C-D functions to calculate the marine fishing capacity of Zhejiang Province from 1994- 2004 by regarding the annual fishing harvest as the output and putting the number of fishing vessels and the professional workforce as inputs. Yunrong *et al*. (2009) applied the SFA and variance analysis method to study the fishing capacity of the light-seiners and light falling-net in the sea areas of Zhongsha and Xisha Islands by using the sampling survey data of fishing ports in 2008.

There are lots of factors affecting the technical efficiency of fishing vessels. For example, James et al. (1995) cited the factors affecting the technical efficiency of US Mid-Atlantic Ocean scallop fisheries, the results of which show that adjusting the use of labor and the annual days of fishing on the sea can effectively improve the technical efficiency. Sharma and Leung (1999) cited the features of fishing vessels in the Hawaiian pelagic fisheries, and the results suggest that the sailors' experience and educational background have a positive impact on the technical efficiency of fishing vessels, and the age of fishing vessels was negatively correlated with the technical efficiency of fishing vessels, and the management right to the fishing vessels also has a significant impact on the technical efficiency of fishing vessels. Tingley *et al*. (2005) utilized the econometric stochastic production frontier (SPF) and the non-stochastic, linear-programming data envelopment analysis (DEA) methodologies to calculate technical efficiency of the English Channel fisheries, and analyzed the influence of factors most affecting technical efficiency by using an SPF inefficiency model and Tobit regression of DEA-derived scores. Pascoe *et al.* (2000) cited the technical efficiency of fishing vessels on the English Channel, and the results show that except the engine power of fishing vessels, the captain's experience and knowledge will affect the level of technical efficiency. Felthoven *et al*. (2009) mentioned the annual days of fishing on the sea stating that the number of sailors and the characteristics of capital have a significant impact on technical efficiency after studying the Bering Sea and Aleutian Islands fishery production. ThiDuy Thanh Pham *et al*. (2014) studied the technical efficiency of gillnet in Da Nang, Vietnam, and results show that the technical efficiency of high-power fishing vessels is higher than the technical efficiency of low-power fishing vessels, and 10.8 percent of potential fishing capacity has not been used.

Fisheries technical efficiency is an important indicator to evaluate the quality of fisheries economic growth. It not only measures the ability of a regional fisheries production level, but also reflects the status of a regional fisheries resources allocation and utilization. The definition of its influencing factors will be helpful to promote the optimal allocation of resources and raise the level of economic growth in fisheries. The marine fishing industry is a major component of marine fisheries, and the study on the level of its technical efficiency has important significance. However, under the multiple pressures, such as the decline of fisheries resources, the energy conservation and emissions reduction of fishing vessels, the industrial structure adjustment of fisheries and so on, it is becoming increasingly difficult to make economic growth in a short-term for fisheries.

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Therefore, the fishing vessels are the important tools for marine fishing industry production, and their status of technical efficiency will affect the ability of fisheries production.

Haizhou Bay once was considered as one of the eight fishing grounds in China, which crosses Jiangsu Province and Shandong Province with an 87 km long coastline and 876 km^2 sea area (WenHai *et al*., 1993). In recent years, similar to the other waters of China, Haizhou Bay is also facing overfishing of fisheries resources and pollution of the marine resources and other issues which have resulted in the continuous decline of fishery resources as well as the increasing pressure of the fisheries economic growth in Haizhou Bay. For example, the number of the main economic fishes is gradually reducing and the emergence of individual miniaturization in Haizhou Bay, such as little yellow croaker and *Trichiurus haumela*, which make some small and low-value fishes become the dominant species as a result of overfishing and resource recession (Tang *et al*., 2011). However, the fishing vessels are the arch criminals for overfishing in Haizhou Bay, and the technical efficiency is one important index of fishing vessels which could reflect some conditions of fishing effort. Hence, the study of the technical efficiency of fishing vessels and its influencing factors could help us find some ways to improve the current condition of the fishery recourses in Haizhou Bay. This paper will be dedicated to figure out the above problems in the following parts and give some advice to the current conditions in Haizhou Bay.

Materials and methods

Data collection

In order to ensure the representative of sample fishing vessels and the convenience of sample scheme, the multiple stratified sampling methods were used in this study. Specifically, according to the engine power and the registry of fishing vessels, 37 pair trawlers, 70 single trawlers, 37 set net fishing vessels, 14 gill net fishing vessels and 10 stow net fishing vessels were stratified and sampled. In the questionnaire, according to the previous introduction and some own features of Haizhou Bay, the input indicators including hull length (m), and engine power (kW) of fishing vessels, the annual days of fishing at sea (days) and the annual total cost (ten thousand RMB), while the output indicator selected for fishing vessels is annual total net income (ten thousand RMB). With the purpose of further analyzing the impacting factors of the technical efficiency of fishing vessels in Haizhou Bay, the indicators of age of fishing vessels (years), the work seniority of the captain of the fishing vessels (years) and the fuel subsidies (ten thousand RMB) were adopted in this study.

Data envelopment analysis

DEA is a kind of extremely flexibility method which can deal with both large as well as small sample size data. In terms of estimating the production frontier, DEA has a relatively low requirement for the sample size, but the

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analysis of results is often better than other methods. So it is more suitable for the technical efficiency analysis of fishing vessels whose production data are not easy to obtain. Therefore, DEA has gotten the key recommendation by food and agriculture organization of the United Nations on a global scale (FAO, 1999). Supposing the fishing vessels in Haizhou bay as constant return to scale (Tobin, 1958), so in our studies we used the CCR model in DEA, its input direction model was outlined as below (similar to the output direction model, no repeat in this paper) :

Suppose the input data of n fishing vessels are X_j and the output data of n fishing vessels are Y_j, $j = 1, K, n$. And $X_j = (X_{1j}, K, X_{mj})^T > 0$ is on behalf m input vectors, while $Y_j = (y_{1j}, K, y_{sj})^T > 0$ is on behalf of s output vectors. Then the production possibility set of fishing vessels is T:

$$T = \{(x,y) | \sum_{j=1}^{n} \lambda_j X_j \le x, \sum_{j=1}^{n} \lambda_j y_j \ge y, \lambda_j \ge 0, j = 1, K, n\} \quad (1)$$

For fishing vessels in Haizhou Bay (x_0, y_0) which is belong to T, the technical efficiency measurements of input direction can be calculated by the following linear programming model, namely:

$$\begin{cases} \min h = h(x_0, y_0) \\ s.t. \sum_{j=1}^{n} \lambda_j X_j \le h x_0 \\ \sum_{j=1}^{n} \lambda_j X_j \ge y_0 \\ \lambda_j \ge 0, j = 1, K, n \end{cases} \quad (2)$$

The dual problem as follows:

$$\begin{cases} \max \mu^T y_0 \\ s.t. \bar{\omega}^T - \mu^T Y_j \ge 0, j = 1, K, n \\ \bar{\omega}^T x_0 = 1 \\ \bar{\omega} \ge 0, \mu \ge 0 \end{cases} \quad (3)$$

According to Formula 2 and Formula 3, we can get the optimal production frontier (SS ') of fishing vessels in Haizhou Bay. As shown in Fig. 1, the fishing vessels which are located in this frontier such as vessel A and vessel B are called DEA efficient, and their technical efficiency value was 1; other fishing vessels which are out of this frontier such as vessel C and vessel D are called DEA inefficient, and their efficiency technical value was between 0 and 1.

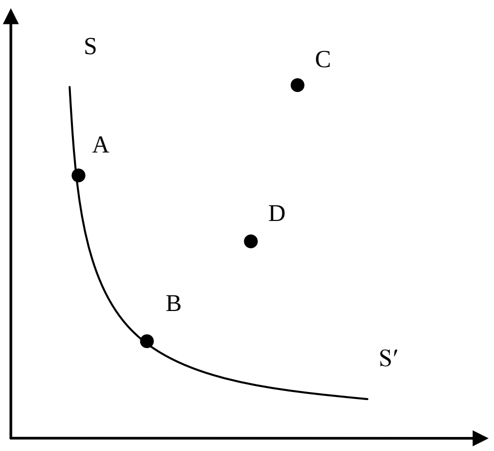

Figure 1: the optimal frontier.

In summary, we can get the relative technical efficiency values of fishing vessels in Haizhou Bay by using the DEA method. In terms of a single fishing vessel, we observed the ways of improving its technical efficiency

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according to the slack variable. However, we couldn't define the main impacting factors of the technical efficiency of fishing vessels in Haizhou Bay. For this reason, we applied multivariate analysis method in this study to define the main factors affecting the technical efficiency of fishing vessels in Haizhou Bay.

Tobit regression model

The parameter estimate is biased and inconsistent if we analyze the regression coefficient by using the Ordinary Least Squares (OLS) because the technical efficiency obtained by DEA in Haizhou Bay are not continuous, and the values are between 0 and 1. In order to avoid this situation, Tobin (1958) proposed the Censored Regression Model which was based on the Maximum Likelihood method in 1958, which is the Tobit Model. In this study, we adopted the cross section Tobit Regression Model to define the main factors affecting the technical efficiency of fishing vessels in Haizhou Bay, namely:

$$Y_i = \beta_0 + \sum \beta_j X_{ji} + \mu_i \quad (4)$$

Wherein, Y_i is the regress and that means the efficiency of each fishing vessel's value; β_0 is the constant term; β_j is the partial regression coefficient; X_{ji} repressor, means impacting factors of fishing vessels' efficiency; μ_i the interference term, and subject to the standard normal distribution. In consideration of the basic situation of the fishing vessels in Haizhou Bay, this study selects the engine power, hull length, and age of the fishing vessels, the captain's working seniority, the annual days of fishing at sea, the annual total cost of the fishing vessels and the fuel subsidies as the factors to analyze the technical efficiency of the fishing vessels, so the Tobit model can be expressed as:

$$Y_i = \beta_0 + \beta_{1X_{1i}} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \mu_i \quad (5)$$

Wherein, Y_i is the technical efficiency of fishing vessels, X_{1i} is the engine power of the fishing vessels (kW); X_{2i} is the hull length of the fishing vessels (m), X_{3i} is the age (years) of the fishing vessels, X_{4i} is the captain's working seniority, X_{5i} is the annual days of fishing at sea, X_{6i} is the total annual cost of the fishing vessels and X_{7i} is the fuel subsidies, β_i is the influence coefficient of all variables to the technical efficiency of each fishing vessel, and μ_i is the stochastic disturbance.

Results

Analysis on technical efficiency of fishing vessels in Haizhou Bay

According to the data obtained from field investigations, descriptive statistics analyses of all the variables were conducted as shown in Table 1. The results showed that the sample data were very discrete which was mainly caused by the engine power of different fishing vessels in Haizhou Bay. According to the DEA model mentioned above, the technical efficiency of 168 fishing vessels sampled in Haizhou Bay were measured (Table 2) to explore the optimal input costs (Table 3) and the maximum theoretical output (Table 4), expecting to clarify the condition of fishing capacity utilization and development potential of fishing vessels in Haizhou Bay.

Table 1: Descriptive statistical analysis of input index and output index.

Variable	Minimum	Maximum	Mean	SD
Engine power (kW)	8.10	350.34	89.75	81.07
Hull length (m)	4.00	36.00	19.36	7.74
Annual days of fishing on the sea (days)	45.00	300.00	178.51	53.02
Total annual cost (ten thousand)	1.25	420.60	53.62	75.46
Total annual net income (ten thousand)	0.06	21.53	4.49	3.80

At present, most of the fishing vessels are in a state of technologically inefficient in Huizhou Bay (Table 2). Among them, the number of fishing vessels whose technical efficiency value is less than 0.7 account for 83.3% of the total number of fishing vessels, the number of fishing vessels whose technical efficiency value is greater than or equal to 0.7 and less than 0.8 account for 6.5% of the total number of fishing vessels; the number of fishing vessels whose technical efficiency is greater than or equal to 0.8 and less than 0.9 account for 3.0% of the total number of fishing vessels; the number of fishing vessels whose technical efficiency value is greater than or equal to 0.9 and less than or equal to 1.0 account for 7.1% of the total number of fishing vessels. Therefore, we concluded that the overall fishing capacity utilization of fishing vessels in Haizhou Bay at present is very low, and there is a serious problem of waste of resources.

Table 2: The distribution interval of technical efficiency of fishing vessels in Huizhou Bay.

Interval	Number of fishing vessels	Percentage
$TE < 0.7$	140	83.3%
$0.7 \leq TE < 0.8$	11	6.5%
$0.8 \leq TE < 0.9$	5	3.0%
$0.9 \leq TE \leq 1.0$	12	7.1%

In terms of the input orientation, the technical efficiency of fishing vessels can be improved by reducing the inputs of fishing vessels while maintaining the current output of the same premise. As shown in Table 3, taking DUM_1 as an example, its technical efficiency is 0.395 which is in technical inefficiency. Therefore, the total annual costs can be decreased from 74600 RMB to 29400 RMB, a drop of 60.59%, while keeping the output of fishing vessels constant. As a whole, the average cost of all the fishing vessels can be decreased from 53620RMB to 23710RMB, a drop of 55.78%.

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Table 3: The actual cost and the optimal cost of fishing vessels in Haizhou Bay.

DUM	Actual cost	Optimal cost	DUM	Actual cost	Optimal cost	DUM	Actual cost	Optimal cost	DUM	Actual cost	Optimal cost
DUM$_{1}$	7.46	2.94	DUM$_{44}$	16.35	5.93	DUM$_{87}$	30.50	15.66	DUM$_{130}$	47.20	47.20
DUM$_{2}$	9.06	2.52	DUM$_{45}$	20.15	4.87	DUM$_{88}$	31.95	11.59	DUM$_{131}$	83.25	36.20
DUM$_{3}$	5.39	1.32	DUM$_{46}$	26.26	5.33	DUM$_{89}$	28.87	0.83	DUM$_{132}$	60.10	16.91
DUM$_{4}$	4.52	1.98	DUM$_{47}$	25.30	2.74	DUM$_{90}$	31.18	13.50	DUM$_{133}$	61.68	11.63
DUM$_{5}$	27.97	27.97	DUM$_{48}$	11.19	4.74	DUM$_{91}$	30.47	13.03	DUM$_{134}$	44.01	14.70
DUM$_{6}$	5.12	3.89	DUM$_{49}$	17.33	7.36	DUM$_{92}$	38.27	3.43	DUM$_{135}$	93.20	26.46
DUM$_{7}$	7.85	1.92	DUM$_{50}$	28.11	12.81	DUM$_{93}$	99.34	47.99	DUM$_{136}$	96.78	30.26
DUM$_{8}$	4.12	4.12	DUM$_{51}$	9.43	1.54	DUM$_{94}$	66.74	26.69	DUM$_{137}$	37.38	19.46
DUM$_{9}$	28.92	28.92	DUM$_{52}$	32.40	8.73	DUM$_{95}$	31.40	7.94	DUM$_{138}$	256.00	33.16
DUM$_{10}$	6.65	3.37	DUM$_{53}$	8.57	3.05	DUM$_{96}$	30.29	13.82	DUM$_{139}$	61.11	29.90
DUM$_{11}$	5.62	1.99	DUM$_{54}$	18.54	7.41	DUM$_{97}$	24.29	12.45	DUM$_{140}$	53.98	21.28
DUM$_{12}$	8.48	6.45	DUM$_{55}$	5.01	2.00	DUM$_{98}$	19.29	6.27	DUM$_{141}$	62.68	19.66
DUM$_{13}$	10.32	10.32	DUM$_{56}$	8.12	1.55	DUM$_{99}$	14.09	11.67	DUM$_{142}$	41.98	10.94
DUM$_{14}$	4.07	4.07	DUM$_{57}$	8.42	5.76	DUM$_{100}$	17.14	6.33	DUM$_{143}$	78.48	9.89
DUM$_{15}$	7.92	5.20	DUM$_{58}$	8.40	2.39	DUM$_{101}$	25.08	17.76	DUM$_{144}$	77.48	31.64
DUM$_{16}$	2.85	1.31	DUM$_{59}$	7.92	0.93	DUM$_{102}$	45.13	16.73	DUM$_{145}$	152.84	50.24
DUM$_{17}$	1.25	1.10	DUM$_{60}$	7.87	2.19	DUM$_{103}$	78.02	33.97	DUM$_{146}$	91.78	17.53
DUM$_{18}$	2.45	2.20	DUM$_{61}$	9.42	1.72	DUM$_{104}$	44.70	24.31	DUM$_{147}$	135.68	46.13
DUM$_{19}$	4.52	1.78	DUM$_{62}$	19.57	15.27	DUM$_{105}$	38.02	21.43	DUM$_{148}$	105.68	46.02
DUM$_{20}$	3.15	1.66	DUM$_{63}$	19.52	15.03	DUM$_{106}$	42.89	1.64	DUM$_{149}$	97.33	33.50
DUM$_{21}$	36.67	3.62	DUM$_{64}$	19.39	12.18	DUM$_{107}$	39.40	8.82	DUM$_{150}$	109.94	51.37
DUM$_{22}$	5.97	0.86	DUM$_{65}$	24.41	6.69	DUM$_{108}$	420.60	95.32	DUM$_{151}$	85.00	61.70
DUM$_{23}$	10.39	5.21	DUM$_{66}$	25.04	13.54	DUM$_{109}$	59.00	25.17	DUM$_{152}$	256.90	256.90
DUM$_{24}$	5.18	3.47	DUM$_{67}$	9.32	2.31	DUM$_{110}$	50.00	28.24	DUM$_{153}$	119.31	65.38
DUM$_{25}$	3.22	1.57	DUM$_{68}$	9.52	0.17	DUM$_{111}$	28.15	9.87	DUM$_{154}$	253.35	196.93
DUM$_{26}$	6.57	1.79	DUM$_{69}$	12.00	1.24	DUM$_{112}$	27.05	14.69	DUM$_{155}$	69.95	21.36
DUM$_{27}$	5.97	2.15	DUM$_{70}$	18.61	6.54	DUM$_{113}$	27.70	6.31	DUM$_{156}$	325.30	47.42
DUM$_{28}$	27.55	6.15	DUM$_{71}$	11.04	7.26	DUM$_{114}$	29.85	5.32	DUM$_{157}$	355.15	126.36
DUM$_{29}$	2.78	2.01	DUM$_{72}$	17.39	8.40	DUM$_{115}$	22.15	7.70	DUM$_{158}$	108.55	24.43
DUM$_{30}$	4.63	2.04	DUM$_{73}$	13.30	4.69	DUM$_{116}$	42.30	24.57	DUM$_{159}$	116.10	28.51
DUM$_{31}$	4.45	4.45	DUM$_{74}$	15.80	5.49	DUM$_{117}$	117.60	76.88	DUM$_{160}$	139.00	37.52
DUM$_{32}$	6.09	1.39	DUM$_{75}$	7.90	1.94	DUM$_{118}$	53.80	18.75	DUM$_{161}$	248.50	156.30
DUM$_{33}$	6.12	2.98	DUM$_{76}$	17.24	17.24	DUM$_{119}$	67.65	15.50	DUM$_{162}$	104.10	24.88
DUM$_{34}$	6.77	3.63	DUM$_{77}$	13.01	0.95	DUM$_{120}$	28.96	2.96	DUM$_{163}$	120.75	115.59
DUM$_{35}$	4.06	0.80	DUM$_{78}$	26.48	7.16	DUM$_{121}$	33.45	1.92	DUM$_{164}$	209.10	71.52
DUM$_{36}$	8.75	0.79	DUM$_{79}$	30.64	14.81	DUM$_{122}$	49.88	0.54	DUM$_{165}$	306.60	57.24
DUM$_{37}$	5.70	2.51	DUM$_{80}$	30.44	18.29	DUM$_{123}$	38.45	10.59	DUM$_{166}$	363.90	253.07
DUM$_{38}$	12.28	6.18	DUM$_{81}$	32.44	20.59	DUM$_{124}$	150.10	150.10	DUM$_{167}$	82.50	51.46
DUM$_{39}$	14.97	5.15	DUM$_{82}$	54.32	24.75	DUM$_{125}$	90.10	52.53	DUM$_{168}$	310.50	310.50
DUM$_{40}$	8.83	3.99	DUM$_{83}$	29.69	14.68	DUM$_{126}$	32.40	12.51	Mean	53.62	23.71
DUM$_{41}$	19.88	5.87	DUM$_{84}$	21.41	5.73	DUM$_{127}$	78.70	36.01			
DUM$_{42}$	6.42	1.37	DUM$_{85}$	15.36	1.10	DUM$_{128}$	51.65	13.91			
DUM$_{43}$	16.60	5.55	DUM$_{86}$	34.90	24.54	DUM$_{129}$	93.75	27.30			

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In terms of the output orientation, the technical efficiency of fishing vessels can be improved by optimizing the allocation of resources while maintaining the current investment remains unchanged. As shown in Table 3, taking DUM$_1$ (others are the same) as an example, the optimal output is 31700 RMB which is 150.30% higher than the actual output while keeping the input of fishing vessels constant. As a whole, the average net income can be increased from 44800 RMB to 102600 RMB while keeping the average input of fishing vessels constant, growth of 129.02%.

Table 4: The actual output and the optimal output of fishing vessels in Haizhou Bay.

DUM	Actual output	Optimal output	DUM	Actual output	Optimal output	DUM	Actual output	Optimal output	DUM	Actual output	Optimal output
DUM$_{1}$	1.25	3.17	DUM$_{44}$	2.61	6.66	DUM$_{87}$	5.18	10.09	DUM$_{130}$	12.82	12.82
DUM$_{2}$	0.89	3.20	DUM$_{45}$	5.26	7.41	DUM$_{88}$	3.52	9.70	DUM$_{131}$	6.47	14.88
DUM$_{3}$	0.74	3.02	DUM$_{46}$	3.76	7.03	DUM$_{89}$	0.31	10.84	DUM$_{132}$	3.95	14.04
DUM$_{4}$	1.37	3.13	DUM$_{47}$	2.96	7.41	DUM$_{90}$	4.25	9.81	DUM$_{133}$	2.76	14.64
DUM$_{5}$	3.27	3.27	DUM$_{48}$	3.02	7.13	DUM$_{91}$	4.42	10.33	DUM$_{134}$	4.33	12.97
DUM$_{6}$	2.49	3.28	DUM$_{49}$	2.53	5.95	DUM$_{92}$	0.91	10.15	DUM$_{135}$	4.50	15.85
DUM$_{7}$	0.84	3.44	DUM$_{50}$	2.98	5.94	DUM$_{93}$	9.72	15.78	DUM$_{136}$	5.53	17.69
DUM$_{8}$	3.24	3.24	DUM$_{51}$	1.10	6.74	DUM$_{94}$	3.49	8.22	DUM$_{137}$	6.75	12.97
DUM$_{9}$	3.26	3.26	DUM$_{52}$	4.02	7.96	DUM$_{95}$	2.77	10.95	DUM$_{138}$	3.83	22.81
DUM$_{10}$	1.71	3.38	DUM$_{53}$	2.71	7.61	DUM$_{96}$	4.97	10.89	DUM$_{139}$	7.15	14.62
DUM$_{11}$	1.16	3.28	DUM$_{54}$	3.51	7.40	DUM$_{97}$	4.52	8.82	DUM$_{140}$	5.37	13.62
DUM$_{12}$	2.59	3.41	DUM$_{55}$	2.22	5.55	DUM$_{98}$	2.63	8.09	DUM$_{141}$	4.61	14.70
DUM$_{13}$	3.57	3.57	DUM$_{56}$	1.23	6.46	DUM$_{99}$	6.07	7.33	DUM$_{142}$	3.88	14.89
DUM$_{14}$	3.18	3.18	DUM$_{57}$	4.04	5.91	DUM$_{100}$	4.40	11.92	DUM$_{143}$	2.08	16.51
DUM$_{15}$	2.26	3.44	DUM$_{58}$	1.75	6.16	DUM$_{101}$	6.19	8.74	DUM$_{144}$	5.97	14.62
DUM$_{16}$	1.23	2.67	DUM$_{59}$	0.69	5.91	DUM$_{102}$	4.34	11.71	DUM$_{145}$	7.60	23.12
DUM$_{17}$	1.36	1.54	DUM$_{60}$	1.95	7.02	DUM$_{103}$	7.11	16.33	DUM$_{146}$	3.04	15.92
DUM$_{18}$	2.71	3.02	DUM$_{61}$	1.15	6.32	DUM$_{104}$	6.57	12.08	DUM$_{147}$	7.05	20.74
DUM$_{19}$	1.69	4.29	DUM$_{62}$	4.79	6.14	DUM$_{105}$	7.09	12.58	DUM$_{148}$	8.05	18.49
DUM$_{20}$	1.97	3.74	DUM$_{63}$	5.35	6.95	DUM$_{106}$	0.47	12.33	DUM$_{149}$	6.43	18.68
DUM$_{21}$	3.14	3.57	DUM$_{64}$	4.36	6.94	DUM$_{107}$	2.83	12.65	DUM$_{150}$	8.52	18.24
DUM$_{22}$	0.61	4.25	DUM$_{65}$	2.74	9.56	DUM$_{108}$	14.67	19.91	DUM$_{151}$	13.12	18.07
DUM$_{23}$	2.82	5.62	DUM$_{66}$	3.68	6.80	DUM$_{109}$	5.25	12.31	DUM$_{152}$	18.28	18.28
DUM$_{24}$	2.88	4.30	DUM$_{67}$	1.97	7.95	DUM$_{110}$	6.71	11.88	DUM$_{153}$	11.48	20.95
DUM$_{25}$	1.93	3.97	DUM$_{68}$	0.14	7.65	DUM$_{111}$	4.01	11.44	DUM$_{154}$	14.24	18.32
DUM$_{26}$	1.25	4.58	DUM$_{69}$	0.84	8.13	DUM$_{112}$	6.98	12.85	DUM$_{155}$	4.90	16.05
DUM$_{27}$	1.64	4.55	DUM$_{70}$	3.10	8.82	DUM$_{113}$	2.55	11.20	DUM$_{156}$	4.19	22.94
DUM$_{28}$	3.03	5.64	DUM$_{71}$	4.09	6.22	DUM$_{114}$	2.09	11.73	DUM$_{157}$	15.34	24.78
DUM$_{29}$	2.48	3.42	DUM$_{72}$	4.13	8.55	DUM$_{115}$	4.19	12.05	DUM$_{158}$	4.26	18.93
DUM$_{30}$	1.63	3.71	DUM$_{73}$	2.51	7.11	DUM$_{116}$	6.21	10.69	DUM$_{159}$	4.75	19.35
DUM$_{31}$	5.48	5.48	DUM$_{74}$	2.51	7.23	DUM$_{117}$	12.65	19.35	DUM$_{160}$	4.02	14.89
DUM$_{32}$	1.17	5.13	DUM$_{75}$	1.56	6.35	DUM$_{118}$	4.84	13.89	DUM$_{161}$	11.65	18.52

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Table 4 continued:

DUM_{33}	2.64	5.42	DUM_{76}	3.92	3.92	DUM_{119}	3.61	15.76	DUM_{162}	4.65	19.45
DUM_{34}	2.81	5.24	DUM_{77}	0.55	7.50	DUM_{120}	0.88	8.62	DUM_{163}	11.26	11.76
DUM_{35}	0.89	4.55	DUM_{78}	2.70	9.98	DUM_{121}	0.71	12.34	DUM_{164}	7.42	21.69
DUM_{36}	0.61	6.72	DUM_{79}	4.51	9.33	DUM_{122}	0.06	5.50	DUM_{165}	5.41	25.46
DUM_{37}	2.11	4.78	DUM_{80}	5.32	8.86	DUM_{123}	3.82	13.86	DUM_{166}	21.53	23.92
DUM_{38}	3.44	6.83	DUM_{81}	5.68	8.95	DUM_{124}	18.46	18.46	DUM_{167}	9.56	15.33
DUM_{39}	4.11	7.71	DUM_{82}	5.86	11.41	DUM_{125}	8.65	14.84	DUM_{168}	21.07	21.07
DUM_{40}	3.04	6.72	DUM_{83}	5.48	11.08	DUM_{126}	4.42	11.45	Mean	4.48	10.26
DUM_{41}	2.58	6.66	DUM_{84}	2.15	8.03	DUM_{127}	6.64	14.51			
DUM_{42}	1.50	7.05	DUM_{85}	0.54	7.51	DUM_{128}	3.69	13.70			
DUM_{43}	2.44	6.66	DUM_{86}	7.27	10.34	DUM_{129}	4.56	15.66			

Analysis on impacting factors of the technical efficiency of fishing vessels in Haizhou Bay

The descriptive statistical analysis of the possible influencing factors, the results as shown in Table 5.

Table 5: The descriptive statistical analysis of variables

Variable	Minimum	Maximum	Mean	SD±
Engine power（X1）	8.10	350.34	89.7503	81.06811
Hull length（X2）	4.00	36.00	19.3551	7.73952
Vessel’s age（X3）	1.00	35.00	9.1905	4.82596
Captain's working seniority（X4）	4.00	47.00	22.9940	8.41406
Annual days of fishing on the sea（X5）	45.00	300.00	178.5119	53.02400
Total annual cost（X6）	1.25	420.60	53.6223	75.45931
Fuel subsidies（X7）	0.73	44.38	10.8155	10.30330

According to the formula 5, we can get the impacting factors on the technical efficiency of fishing vessels which is shown in Table 6.

Table 6: The Tobit regression results the technical efficiency of fishing vessels in Haizhou Bay.

Variable	Coefficient	Standard deviation	Wald chi-square	*p* value
Constant（X_0）	0.7308	0.1011	52.2062	0.0000
Engine power（X_1）	-0.0007	0.0019	0.1398	0.7085
Hull length（X_2）	-0.0094	0.0049	3.6611	0.0557
Vessel’s age（X_3）	-0.0009	0.0039	0.0505	0.8222
Captain's working seniority（X_4）	0.0026	0.0022	1.4337	0.2312
Annual days of fishing on the sea（X_5）	-0.0011	0.0003	11.5793	0.0007
Total annual cost（X_6）	0.0014	0.0004	14.6074	0.0001
Fuel subsidies（X_7）	0.0038	0.0142	0.0724	0.7878

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As shown in Table 6, the regression coefficients of engine power, hull length and vessel age are -0.0007, -0.0094 and -0.0009 respectively, which were all negative, indicating that all of them were negatively correlated with the technical efficiency of the fishing vessels. The regression coefficient of the working seniority of the Captain and fuel subsidies were 0.0026 and 0.0038 respectively which are both positive, indicating that both of them are positively correlated with the technical efficiency of the fishing vessels. However, the *p* value of engine power, hull length, vessels age and fuel subsidies were 0.7085, 0.0557, 0.8222 and 0.7878 which were not significant under the 5% significant level. In other words, engine power, hull length, vessel age and fuel subsidies were not the main impacting factors on technical efficiency of the fishing vessels.

The regression coefficient of annual days of fishing at sea in the Haizhou Bay is -0.0011 which indicates that the annual days of fishing at sea is negatively correlated with the technical efficiency of fishing vessels. Besides, the *p* value of annual days of fishing at sea is 0.007 which is significant at 5% significance level. Specifically, to a certain extent, the technical efficiency of fishing vessels will decrease to 0.0011 if the annual days of fishing at sea increases by one day supposing the other factors remain unchanged (Table 6). Recently, the status of fisheries resources in Haizhou Bay has been improved apparently by means of the fishing moratorium, restocking, construction of artificial reefs and marine environmental protection, and many other means. However, the bearing capacity of fisheries recourses in Haizhou Bay is becoming increasingly weak, so the technical efficiency of a pair trawler tends to reduce gradually with the number of days at sea.

The regression coefficient of total annual costs is 0.0014 which indicates that the total annual cost is positively correlated with the technical efficiency of fishing vessels. Besides, the P value of total annual cost is 0.001 which is significant at the 5% significance level. Specifically, to a certain extent, the technical efficiency of fishing vessels will increase to 0.0014 if the total annual costs increases to ten thousand RMB, supposing the other factors remain unchanged (Table 6). The above means that the total annual costs of all the fishing vessels in Haizhou Bay are lower than the optimal total annual cost. Therefore it can be concluded that the total annual costs of all the fishing vessels should be decreased in order to get a higher technical efficiency as a whole.

Discussion

Index selection and evaluation methods of technical efficiency

Currently, there are four principal methods of efficiency analyses: least-squares (LS) econometric production models, total factor productivity (TFP) indices (Tornqvist/Fisher), data envelopment analysis (DEA) and stochastic frontiers (SF) (Coelli, 2005). Technical efficiency is generally measured by using DEA or SF methods.

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Although there are some advantages of SF method over DEA, for example, SF method can account for noise and can be used to conduct conventional tests of hypotheses, the DEA method does not need to specify a distributional form for the inefficiency term and specify a functional form for the production function (or cost function, etc.). In addition, the DEA method has the merits of strong objectivity, easy to use, obvious economic significance, and the analysis effects are greatly superior to the production function method, so it has become a kind of important analytical tool and means of management science, systems engineering, decision analysis and evaluation technology and other fields (Zhaoqun, 2016). As a result, it has attracted much widespread attention as it arose in different social sectors such as culture, economy, science and technology (Zheng, 2007; Han, 2012; Wang and Gao, 2012; Li, 2013). During the last decades, the DEA method received greater emphasis in both theoretical research and practical application. In this study, the CCR model based on constant return to scale was used to evaluate the technical efficiency of fishing vessels in Haizhou Bay. Then this study defines its influence factors by using Tobit regression. The result of this paper has an important practical significance on guiding the sustainable development of fisheries resource in Haizhou Bay. However, fisheries are a complex, adaptive and dynamic system (Fuqing, 1999). The fishing vessels in Haizhou Bay are not in constant return to scale all the time. The influence factors of the technical efficiency of fishing vessels include not only the fishing vessels' own features but also some relevant social, economic and other factors. Therefore, we suggest that its technical efficiency and its influencing factors are further studied under a dynamic, open and larger system perspective.

Selection of decision making units

In the studies of technical efficiency of fishing industry, the majority of scholars reviewed the changing tendency of annual technical efficiency in all regions under a macro perspective by using the annual data and regarding the regions as the DUMs so that they can get the status of fishing industry's technical efficiency in different years and regions. In addition, some scholars put the years as the DUMs and put all kinds of total input and total output as the input and output indexes of DUMs, and then analyzed the corresponding time series data analysis by DEA method to solve the annual technical efficiency of fishing industry (Zheng *et al*., 2009). In this study, we used the single fishing vessel as the DUM to calculate its technical efficiency by using the DEA method, and further explore the main factors that influence the technical efficiency of fishing vessels which is helpful for all decision makers to understand the technical efficiency level of the fishing vessels with different engine power and define the factors that have relevant influence from the micro perspective in order to help them further master the actual status of the fishing vessels of different

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operation types and make the policy making more targeted and feasibility. Compared to the existing related research, it is not difficult to find that, the data in this study is cross sectional data instead of panel data like other related studies. Hence, this study is just a static research rather than a dynamic research, which cannot reflect the status of annual changing trends of the technical efficiency and the factors that influence technical efficiency of fishing vessels in Haizhou Bay. Therefore, we should make up for this deficiency in further studies so that the result can reflect the actual dynamics of the fishery in Haizhou Bay, comprehensively.

Research significance and conclusions

The improvement of fisheries efficiency depends on the technological progress of fisheries and the improvement of its technical efficiency. The improvement of fisheries technical efficiency can improve the economic benefits of fisheries and promote the sustainable growth of fisheries economy. Among the measures taken, we need not only sound policies implemented by the government or department, but also all kinds of science and technology such as the technical support of extended service forms, and research techniques that can improve the production efficiency and technological research and development that can preserve the ecological environment. However, due to the lack of resources and environmental pollution problems, it is becoming increasingly difficult to improve fisheries production efficiency and promote the growth of fisheries economy through technological change or technological progress in a short time (Chaoqing, 2007; Yuke, 2009; Handuo, 2013). Hence, the improvement of technical efficiency is of great importance for the improvement of production efficiency and the growth of fisheries economy. In other words, it is more effective to improve the technical efficiency than to archive the technical progress or introduce advanced technology under the background of the decline of fisheries resources.

Therefore, improving the utilization level of technology will be helpful to improve the utilization efficiency of the existing resources, so as to get more output by using the same input (such as DMU_1 in Table 4). By considering the influence factors of technical efficiency roundly and utilizing the existing resources comprehensively can help to improve the technical efficiency and economic benefits of fisheries, and further improve the utilization efficiency of resources and the income level of fishermen. Finally, it will improve competitiveness of fisheries and promote its sustainable development. Currently, the majority of the fishing vessels in Haizhou Bay are in technical inefficiency and the overall technical efficiency of fishing vessels is very low, and there are irrational allocation of resources and serious wastage of resources. In terms of improving the technical efficiency of one certain fishing vessel, from the input point of view, we can reduce the input reasonably so as to avoid wasting rescourses while the output is the same.

In terms of the general present situation of fishing vessels in Haizhou Bay, we can reduce the annual days at sea and increase the annual total costs such as implementing the fishing moratorium, reducing the days at sea during the season of poor fisheries resources and increasing the corresponding costs which can improve the overall technical efficiency of fishing vessels in Haizhou Bay.

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