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Evaluation and Comparison of Marine Sci-tech Innovation Ability of 11 Coastal Provinces in China: A Case Study of Guangdong

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Abstract Through building an indicator system for evaluating the marine sci-tech innovation ability of China's coastal provinces, this paper made a comparative analysis on marine sci-tech innovation ability of 11 coastal provinces in 2011-2013 by the principal components analysis (PCA) method. It found these coastal regions can be divided into three levels. Guangdong Province belongs to the first level because its marine sci-tech innovation ability is relatively high. On this basis, it analyzed changes in marine sci-tech innovation ability of 11 coastal provinces with the aid of DEA's Malmquist productivity index model. Results indicate that the overall marine sci-tech innovation ability of 11 coastal provinces is rising, but there is significant difference between provinces and the influence of regional economic development level is not considerable. Technical progress is main driver for promoting marine sci-tech innovation ability of Guangdong Province and major factor influencing ranking of total factor productivity.

Key words Marine sci-tech innovation ability, Innovation ability, Innovation ability evaluation, PCA, Malmquist productivity index model

1 Introduction

Existing researches about marine science and technology mainly focus on following aspects. In comprehensive evaluation of marine sci-tech innovation, using basic idea of combined model, Li Bin *et al*. introduced Kendall consistency test and fuzzy Borda number rule, built a combined model consisting of PCA, gray correlation analysis, and fuzzy comprehensive evaluation method, and made a comprehensive evaluation on marine sci-tech innovation ability of Shandong Peninsula Blue Economic Zone, which effectively avoids drawbacks of traditional single evaluation method and makes the evaluation results more scientific and comprehensive [1]. With the aid of the balance score card (BSC), Li Tuochen *et al*. established a BSC evaluation model for sci-tech innovation ability of China's marine high sci-tech industries, determined the weight of factor in the indicator system by grid method and Borda number analysis method, and made an evaluation of sci-tech innovation ability of China's marine high sci-tech industries using fuzzy comprehensive evaluation method and Delphi method [2]. Furman *et al*. evaluated marine sci-tech innovation ability from factors influencing marine sci-tech efficiency and stated that like R&D resource input, environment and policy are essential factors influencing performance of machine sci-tech output [3]. In analysis of marine sci-tech competitiveness, foreign scholars discuss contribution of marine sci-tech innovation ability to marine economy from the perspective of marine industry [4-5], while domestic scholars mainly apply PCA [6], Analytic Hierarchy Process (AHP) [7], and gray correlation analysis [8]. Common feature of these researches lies in building an evaluation indicator system for marine sci-tech competitiveness of China and coastal provinces, calculating score of each indicator and comprehensive score through assigning weight, then ranking and evaluating marine sci-tech competitiveness of China's coastal provinces, and finally coming up with recommendations. Researches about the relation between marine sci-tech and marine economic development are few and mainly lie in two aspects: (i) coordination, and (ii) marine sci-tech input and economic growth. Wang Zeyu *et al*. made a comprehensive evaluation of the relation between marine sci-tech innovation ability and marine economic development level of China's coastal regions, built the coordination model according to measurement and evaluation results, and measured the coordination degree [9]. Using PCA, Yin Kedong *et al*. measured and evaluated comprehensive level of marine science and technology and marine economy sustainable development in Shandong Province, and accordingly measured the coordination with the aid of coordination relation model [10]. Nasierowski *et al*. and Eric C. Wang made an empirical analysis on marine sci-tech input performance using DEA method and results indicate that R&D and sci-tech innovation scale play a significant role in regional marine economic growth [11-12]. Some scholars made econometric analysis on panel data of 11 coastal regions or single coastal province by C-D production function expansion model [13], Cobb-Douglas production function [14], and double factor error panel model [15]. In addition, some

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scholars analyzed and studied marine sci-tech innovation efficiency of a certain coastal province or region by DEA method with reference to practice of foreign scholars, and obtained ideal research results [16-19].

In sum, existing research findings provide excellent ideas for our in-depth study on matters related to marine science and technology, especially the pertinent policy recommendations will provide excellent theoretical guidance and practical value. However, there are few researches about the relation between marine sci-tech innovation ability and marine sci-tech ability and marine economy of Guangdong Province. Therefore, it is necessary to make quantitative analysis on influence of marine sci-tech innovation ability on marine economic development of Guangdong Province with the aid of great historical opportunity of Guangdong Province building state-level marine economy comprehensive pilot zone. Using PCA, we measured and evaluated marine sci-tech innovation ability of 11 coastal provinces in China. On this basis, we analyzed changes in marine sci-tech innovation ability of 11 coastal provinces with the aid of DEA's Malmquist productivity index model, so as to find out the marine sci-tech innovation ability level and efficiency and come up with pertinent recommendations according to research results.

2 Measurement of marine sci-tech innovation ability of coastal provinces

2.1 Building an evaluation indicator system for marine sci-tech innovation ability of coastal provinces To evaluate marine sci-tech innovation ability of Guangdong Province in an objective, scientific and comprehensive way, and analyze position of marine sci-tech innovation ability of Guangdong Province in major coastal provinces of China, it is necessary to establish a complete set of evaluation indicator system that can reflect marine sci-tech innovation ability from different points of views. Xu Jin, Xie Ziyuan and Jiang Bao *et al*. took scientific research funds and talents as marine sci-tech innovation input variables, number of papers, writings, and patents for invention [20-22], and Bai Fuchen took per capita number of papers, programs, writings, and patents of the workers as innovation efficiency evaluation indicators [10]. In view of this, adhering to the principle of science, comprehensiveness, operability, and comparability, we established an evaluation indicator system from marine sci-tech input, output, and efficiency. This indicator system includes 9 indicators classified into 3 types. It can objectively and comprehensively reflect basic connotation of marine sci-tech innovation ability and the specific indicator arrangement is listed in Table 1.

Table 1 Evaluation indicator system for marine sci-tech innovation ability of coastal provinces

Level I indicators		Level II indicators//%	No.
Marine sci-tech innovation ability of coastal provinces	Marine sci-tech input	Proportion of gross income of marine scientific research funds	X1
		Proportion of marine sci-tech workers	X2
		Proportion of sci-tech workers with senior title	X3
		Proportion of number of programs of marine scientific research institutions	X4
	Marine sci-tech output	Proportion of number of patents for invention of marine scientific research institutions	X5
		Proportion of scientific papers published	X6
		Proportion of number of patents granted	X7
	Marine sci-tech efficiency	Per capita number of programs of marine sci-tech workers	X8
		Per capita number of papers issued by people engaged in marine sci-tech activities	X9
		Proportion of sci-tech services to number of programs	X10

Note: unit of all indicators in this paper adopts percentage (%).

2.2 Data source and processing results of original data The data in this study were selected from *China Marine Statistical Yearbook* (2011-2013), according to which we collected corresponding statistical data of 11 coastal provinces in 2011-2013, as listed in Table 2.

2.3 PCA based evaluation on marine sci-tech innovation ability of coastal provinces

2.3.1 Comprehensive evaluation on marine sci-tech innovation ability of coastal provinces in 2013. With the aid of statistical software SPSS 21.0, we made principal component analysis on data of 2013 for 11 coastal provinces, obtained corresponding characteristic values and contribution rate of every marine sci-tech innovation ability indicator. Three indicators have characteristics values higher than 1 and the Accumulated Variance Contribution Rate is up to 88.194%, conforming to the principle of the proportion of variance explained by principal components to total variance higher than 85%, indicating that three principal components take up 88.194% of indicator information and can be taken as comprehensive indicators for reflecting marine sci-tech innovation ability of coastal provinces, as listed in Table 3.

Then, we calculated the weighted sum of three principal components taking the accumulated variance contribution rate as the weight, obtained the comprehensive score of marine sci-tech innovation ability of 11 coastal provinces, ranked then according to respective score, and found that Guangdong had the highest marine sci-tech innovation ability in 2013, followed by Shandong and Shanghai. The marine sci-tech innovation ability of Jiangsu, Tianjin, Liaoning, Zhejiang, and Fujian remained the intermediate level, and Jiangsu and Tianjin had marine sci-tech innovation ability lower than the average level, while Liaoning, Zhejiang, and Fujian had marine sci-tech innovation ability higher than the average level. Hebei, Guangxi, and Hainan hade low marine sci-tech innovation ability, lower than the average level.

Table 2 Indicators for marine sci-tech innovation ability of coastal provinces in 2011 -2013

2013	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Tianjin	6.35	6.97	5.81	4.47	1.36	5.09	2.88	25.42	40.22	29.34
Hebei	0.48	1.47	1.62	0.51	0.04	2.68	0.22	14.13	84.37	20.51
Liaoning	4.40	5.51	4.56	2.19	11.86	2.86	9.18	16.23	28.76	12.17
Shanghai	11.24	9.88	8.53	6.47	13.76	7.32	15.84	26.77	39.11	21.99
Jiangsu	7.80	7.70	5.83	12.02	1.91	6.22	3.82	63.83	59.02	8.86
Zhejiang	5.11	4.50	4.15	3.21	1.08	3.05	2.15	29.14	36.18	28.54
Fujian	3.28	2.85	2.45	3.84	1.13	2.09	0.58	54.98	34.48	15.23
Shandong	12.29	10.13	9.00	10.06	5.17	12.10	10.20	40.60	63.16	8.45
Guangdong	6.89	8.40	7.89	14.22	9.96	12.59	8.96	69.22	79.76	22.37
Guangxi	0.36	1.18	0.59	0.69	0.20	0.63	0.47	23.87	29.33	3.77
Hainan	0.39	0.51	0.14	0.30	0.05	0.41	0.18	23.96	38.55	2.17
2012	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Tianjin	6.86	6.91	6.04	3.76	1.25	4.92	3.28	20.73	37.21	30.60
Hebei	0.57	1.48	1.78	0.47	0.10	3.57	0.05	12.09	96.40	29.85
Liaoning	4.53	5.66	4.51	2.03	13.17	2.87	8.22	13.69	27.86	13.10
Shanghai	11.52	9.46	8.54	7.68	15.03	7.09	19.58	30.89	36.63	26.23
Jiangsu	7.43	8.80	6.23	12.05	0.69	7.11	3.08	52.14	56.87	12.51
Zhejiang	4.8	4.31	4.12	3.09	0.76	3.20	2.01	27.26	37.20	39.32
Fujian	2.27	2.73	2.43	4.40	1.31	2.61	0.98	61.29	41.94	16.59
Shandong	10.96	9.93	9.45	10.36	5.39	12.09	10.43	39.71	61.63	9.48
Guangdong	7.51	8.25	7.46	13.53	6.79	9.98	7.64	62.47	60.53	21.98
Guangxi	0.36	1.24	0.57	0.73	0.02	0.91	0.93	22.32	38.90	10.58
Hainan	0.23	0.49	0.11	0.59	0.02	0.36	0.24	45.41	39.16	8.33
2011	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Tianjin	8.17	6.97	5.64	3.60	1.10	4.67	2.90	19.66	34.47	35.67
Hebei	0.56	1.54	1.77	0.38	0.10	0.63	0.07	9.38	18.07	31.37
Liaoning	4.41	5.63	5.11	1.91	13.78	2.21	7.89	12.90	19.63	10.12
Shanghai	11.57	9.52	8.65	8.08	15.59	7.22	20.92	32.28	35.35	21.23
Jiangsu	6.76	8.73	6.97	12.00	1.05	7.48	4.99	52.30	42.65	16.03
Zhejiang	4.38	3.94	4.06	2.92	0.53	3.16	1.69	28.15	39.37	31.55
Fujian	2.23	2.84	2.44	4.61	1.07	2.44	0.67	61.85	35.83	7.57
Shandong	9.67	10.20	9.47	10.08	3.76	11.55	8.57	37.62	56.16	9.13
Guangdong	7.84	7.89	7.80	12.46	8.59	11.79	7.76	60.04	73.29	23.30
Guangxi	0.39	1.26	0.52	0.82	0.00	0.73	0.00	24.89	31.63	11.71
Hainan	0.21	0.56	0.15	0.42	0.00	0.25	0.07	28.43	20.93	1.79

Data source: *China Marine Statistical Yearbook* (2011 -2013).

Table 3 Total variance explained

Component	Initial characteristic value			Loading the extracted sum of squares			Loading the rotated sum of squares		
	Total	Variance %	Cumulative %	Total	Variance %	Cumulative %	Total	Variance %	Cumulative %
1	6.106	61.057	61.057	6.106	61.057	61.057	4.756	47.555	47.555
2	1.692	16.918	77.975	1.692	16.918	77.975	2.908	29.083	76.638
3	1.022	10.219	88.194	1.022	10.219	88.194	1.156	11.556	88.194

2.3.2 Rank of marine sci-tech innovation level of coastal provinces in 2011-2013. Similarly, with the aid of statistical software SPSS 21.0, we made principal component analysis on data of 11 coastal provinces and ranked them according to their respective comprehensive scores, as listed in Table 4.

From Table 4, we divided comprehensive scores of marine sci-tech innovation ability of 11 coastal provinces into 3 levels. The first level: Guangdong, Shandong, and Shanghai. These 3 provinces had high marine sci-tech innovation ability and ranked the first position for three consecutive years. The second level:

Jiangsu, Tianjin, Liaoning, Zhejiang, and Fujian. These 5 provinces remained the intermediate level and their ranks fluctuated slightly in 2011 – 2013. The third level: Hebei, Guangxi, and Hainan. These 3 provinces had low marine sci-tech innovation ability without big changes in ranks. In 2011 – 2013, the division of these 3 levels was relatively stable and there was basically no change, but there was only slight changes in ranks within each level. Comparing the last rank in the first level with the first rank in the second level, we can find that there is a large gap between the first level and the second level and between the second and the third level, which reflects significant gap in marine sci-tech innovation ability between each level.

Table 4 Comprehensive scores and rank of marine sci-tech innovation ability of coastal provinces in 2011 – 2013

Component	2013		2012		2011	
	Comprehe-nsive score	Rank	Comprehe-nsive score	Rank	Comprehe-nsive score	Rank
Guangdong	0.81	1	0.72	2	0.79	1
Shandong	0.71	2	0.80	1	0.69	3
Shanghai	0.71	3	0.67	3	0.71	2
Jiangsu	0.27	4	0.41	4	0.40	4
Tianjin	0.06	5	0.12	5	0.12	5
Liaoning	–0.05	6	–0.30	7	–0.18	7
Zhejiang	–0.16	7	–0.07	6	–0.14	6
Fujian	–0.35	8	–0.37	9	–0.33	8
Hebei	–0.48	9	–0.32	8	–0.61	9
Guangxi	–0.74	10	–0.81	10	–0.65	10
Hainan	–0.78	11	–0.85	11	–0.80	11

In the first level, Shanghai had relatively stable marine sci-tech innovation ability and basically remained in the third rank; rank evolution of Guangdong and Shandong took on reverse direction. In 2011, Guangdong ranked in the first place; in 2012, Shanghai topped Guangdong, and in 2013, Guangdong rose to the first place again. In marine sci-tech input, there was little gap between Guangdong, Shandong, and Shanghai. Shandong had advantages over Guangdong and Shanghai in workers and senior title personnel of marine sci-tech field, indicating marine talent advantage is an important magic weapon for Shandong maintaining marine sci-tech innovation ability. In marine sci-tech output, the number of programs of Guangdong marine scientific research institutions was slightly higher than Shandong and Shanghai, indicating that scientific research environment is an essential factor influencing marine sci-tech innovation ability. In marine sci-tech efficiency, Guangdong always remained the leading position in both the per capita number of programs of workers and number of papers published by personnel engaged in marine sci-tech activities. Therefore, when the sci-tech input is equal, high sci-tech efficiency and excellent sci-tech environment are key factors for Guangdong surpassing Shanghai. Although Shandong Province ranked in the second place, from the development trend, there is widening gap between Shandong and Guangdong. Shandong has advantage in marine talents, but its proportion of marine sci-tech output indicators still has a widening gap with Guangdong, especially in marine sci-tech efficiency indicator, such as per capita programs of workers, proportion of sci-tech service to programs. Therefore, the marine sci-tech efficiency is an essential indicator for evaluating marine sci-tech innovation ability of Shandong or the marine sci-tech efficiency is major factor for Guangdong ranking the first place in coastal provinces of China.

In the second level, there was no change in rank of Jiangsu and Tianjin, and Liaoning and Zhejiang basically remained in the sixth and seventh place. Jiangsu remained in the fourth place mainly due to rapid growth of per capita programs of workers in 2012-2013 from 52.14% to 63.83%, obviously faster than the average growth of other provinces. Besides, the per capita papers published by workers of Jiangsu engaged in marine sci-tech activities also rose rapidly. Tianjin remains in the fifth place, but its indicators take on steadily rising trend and its marine sci-tech innovation strength is gradually strengthened. In the third level, there was no change in rank of Hebei, Guangxi and Hainan, indicating that the marine sci-tech innovation of these 3 provinces remains at the national low level.

3 Comparative analysis on marine sci-tech innovation efficiency of coastal provinces

3.1 Dynamic analysis on marine sci-tech innovation efficiency According to above listed marine sci-tech input and output indicators for marine sci-tech innovation ability of Guangdong, we substituted original data of indicators into Malmquist productivity index model, calculated using DEAP 2.1, and obtained measurement results of total factor productivity index of Guangdong and 11 coastal provinces, as listed in Table 5 and Table 6. From Table 5, we can know that the marine sci-tech innovation efficiency of coastal provinces rose 3.4% in the first period and dropped 1.2% in the later period, mainly due to decline of technical progress and technological efficiency, and the decline rate of technical progress greater than technological efficiency, indicating that technical progress greatly impedes marine sci-tech innovation ability. However, on the whole, marine sci-tech innovation efficiency is rising. From Table 6, we can see that there was significant change in marine sci-tech innovation efficiency of Guangdong, the change trend was first rise and then fall, and the rising level was higher than the average level. From the changes in technological efficiency and technical progress, the former keeps stable level, while the latter takes on growth trend, indicating that the contribution of technical progress to marine sci-tech innovation efficiency is greater than technological efficiency, such improvement is mainly due to influence of changes of scale efficiency and pure technological efficiency.

Table 5 Changes in marine sci-tech innovation efficiency of 11 coastal provinces in 2011-2013

Year	Changes in technical efficiency (effch)	Changes in technical progress (techch)	Changes in pure technical efficiency (effch)	Changes in scale efficiency (sech)	Changes in total factor productivity (tfpch)
2011 – 2012	1.042	1.184	1.029	1.013	1.234
2012 – 2013	0.969	0.941	0.975	0.993	0.912
Mean	1.005	1.056	1.001	1.003	1.061

Table 6 Changes in marine sci-tech innovation efficiency of Guangdong Province in 2011 – 2013

Year	Changes in technical efficiency (effch)	Changes in technical progress (techch)	Changes in pure technical efficiency (effch)	Changes in scale efficiency (sech)	Changes in total factor productivity (tfpch)
2011 – 2012	1.000	0.964	1.000	1.000	0.964
2012 – 2013	1.000	1.143	1.000	1.000	1.143
Mean	1.000	1.054	1.000	1.000	1.054

3.2 Dynamic analysis on marine sci-tech innovation efficiency of coastal provinces

3.2.1 Analysis on overall situations of marine sci-tech innovation efficiency. We calculated efficiency indicators of marine sci-tech innovation of coastal provinces in 2011-2013 with the aid of DEAP 2.1 software. The results were listed in Table 7. On the whole, the total factor productivity (TFP) of 11 coastal provinces increased 6.1%, in which technical efficiency grew 0.5% and technical progress grew 5.6%, indicating that the TFP growth mainly gives the credit to growth of technical progress. From the decomposition of technical efficiency, pure technical efficiency grew 0.1% and scale efficiency grew 0.3%, indicating coastal provinces lay equal stress on scale efficiency growth and pure technical efficiency growth. From the perspective of provinces, marine sci-tech input-output efficiency of Zhejiang, Fujian and Shanghai is relatively low, while other provinces have high marine sci-tech input-output efficiency, reflecting significant regional difference in marine sci-tech innovation ability, which is consistent with conclusions of Jiang Bao *et al.* (2015), reflecting stability of research findings to a certain extent [22]. It should be noted that underdeveloped provinces such as Hebei and Guangxi have marine sci-tech input-output efficiency ranking the first place, indicating the influence of regional marine sci-tech input-output efficiency from regional economic development level is not significant.

3.2.2 Difference analysis on marine sci-tech innovation efficiency of coastal provinces. (i) In terms of technical efficiency, the mean value of coastal provinces in 2011-2013 was 1.005, higher than 1, indicating high technical efficiency and full use of marine sci-tech innovation input resources. Hebei and Shandong ranked in the leading position, Guangxi, Tianjin, Zhejiang and Fujian ranked in the last position, and the rest provinces kept stable level and Guangdong was in this scope. (ii) In terms of technical progress, the technical progress index of Fujian and Shanghai was lower than 1, showing decline of technical progress level, and the rest provinces were higher than 1, Guangdong ranked in the fourth place. This indicates that technical progress of Guangdong becomes major factor promoting TFP growth. (iii) In terms of pure technical efficiency, the index value of Tianjin, Fujian and Zhejiang was smaller than 1, reflecting decline in pure technical efficiency, while other provinces kept basically stable level in this index, indicating that the existing marine sci-tech management mode is objectively not consistent with increase in marine sci-tech efficiency. Therefore, coastal provinces with stable value of this index should consolidate marine sci-tech input resource elements in future marine sci-tech innovation development, to gradually realize optimum combination of resource allocation and increase resource utilization efficiency. (iv) In terms of scale efficiency, the mean value of coastal provinces was 1.005, higher than 1, indicating that marine sci-tech innovation of coastal provinces has formed scale effect to a certain extent. However, this index value of most coastal provinces kept stable, only Hebei, Shandong and Zhejiang rose in scale efficiency, indicating that the scale effect brought by marine sci-tech innovation development of coastal provinces including Guangdong is not significant. (v) In terms of TFP, the TFP of most coastal provinces was rising in most coastal provinces, only Shanghai, Zhejiang and Fujian were smaller than 1, showing a decline trend. TFP of Guangdong ranked the third place, and the efficiency change index was 1.050. In existing average technical conditions, input elements obtained maximum output, and there was no outstanding improvement in technical efficiency, while technical progress index was relatively high, technical progress rate reached 5.0%, which directly brought about TFP increase.

To more visually analyze contribution of each indicator to TFP change of coastal provinces, we plotted the stacked column diagram for contribution of each indicator to TFP of coastal provinces, as shown in Fig. 1.

Table 7 Malmquist efficiency index and decomposition indicators of coastal provinces in 2011 – 2013

DMUi	Changes in technical efficiency (effch)	Changes in technical progress (techch)	Changes in pure technical efficiency (effch)	Changes in scale efficiency (sech)	Changes in total factor productivity (tfpch)
Tianjin	0.976	1.052	0.991	0.985	1.027
Hebei	1.257	1.448	1.206	1.042	1.820
Liaoning	1.000	1.025	1.000	1.000	1.025
Shanghai	1.000	0.899	1.000	1.000	0.899
Jiangsu	1.000	1.037	1.000	1.000	1.037
Zhejiang	0.923	1.040	0.905	1.021	0.960
Fujian	0.908	0.997	0.940	0.966	0.905
Shandong	1.037	1.011	1.000	1.037	1.049
Guangdong	1.000	1.050	1.000	1.000	1.050
Guangxi	0.988	1.090	1.000	0.988	1.077
Hainan	1.000	1.041	1.000	1.000	1.041
Mean	1.005	1.056	1.001	1.003	1.061

Data source: results of software deap2.1.

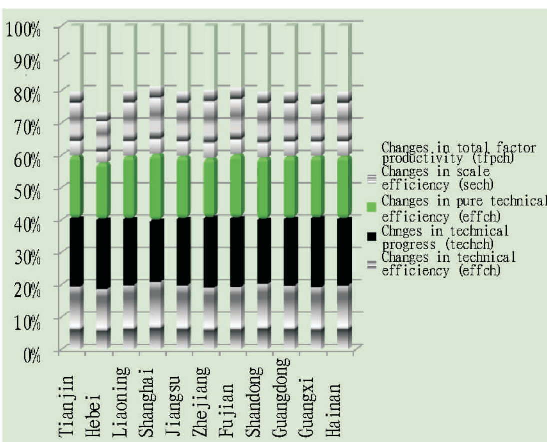

Fig. 1 Contribution of each decomposition indicator to TFP changes of coastal provinces

4 Conclusions and policy recommendations

4.1 Conclusions (i) The marine sci-tech innovation ability of 11 coastal provinces is improved on the whole, but there is significant difference at provincial level and the influence from regional economic development level is not significant. For the marine sci-tech input-output efficiency, the highest is Hebei, Jiangsu, and Guangdong, followed by Hainan, Tianjin, and Shandong, and the last is Guangxi, Liaoning, Zhejiang, Fujian, and Shanghai. Provincial difference is possibly due to insufficient technical progress, no improvement in technical utilization efficiency, insufficient input, or no certain scale effect. Besides, this problem also indicates some defects of allocation and utilization, marine sci-tech management level, and management technologies of marine sci-tech resources in coastal provinces. (ii) In terms of changes in marine sci-tech innovation efficiency, technical progress is major driver for improvement in marine sci-tech innovation ability of Guangdong Province. From Table 7, we can know that TFP of Guangdong is rising and technical efficiency keeps stable, but technical progress gradually rises, which is obviously benefited from constant improvement in technical progress. (iii) In terms of Malmquisit efficiency index and decomposition indicators, technical progress is a major factor influencing ranking of TFP. From analysis of Malmquisit efficiency index of coastal provinces and decomposition indicators, it can be seen that TFP of Guangdong ranks the third place, its TFP value is 1.033, the reason for this is due to rapid growth of technical progress, up to 3.3%, and technical efficiency remains stable possible because there is no significant improvement in pure technical efficiency and scale efficiency, and there are relatively large differences with some coastal provinces. This indicates that technical progress plays an essential role in improving marine sci-tech innovation ability, directly influences ranking of TFP, while the increase of technical efficiency slightly promotes TFP when the technical progress is not obvious.

4.2 Policy recommendations (i) In view of regional difference in marine sci-tech input-output efficiency, it is necessary to formulate scientific marine sci-tech development strategies and marine sci-tech resource macro-management policies. Firstly, in regions with high marine sci-tech input-output efficiency, it is recommended to continue to bring into play leading role of technical progress, and attach great importance to pure technical efficiency. Especially, it is expected to form powerful scale effect to promote technical efficiency, to realize the goal of technical progress and technical efficiency jointly promoting benign growth of TFP. Major measures include increasing input in marine sci-tech research and development and new and high technologies, expanding diversified channels for raising scientific research funds, bringing into play leading role of enterprises in marine sci-tech innovation, enhancing connection between government, industry, university, and research, accelerating conversion of new and high technical achievements, and promptly summarizing and extending successful practice and advanced experience in marine sci-tech innovation. Secondly, in regions with intermediate marine sci-tech input-output efficiency, it is recommended to increase input of technical progress and accelerate technical utilization efficiency of marine sci-tech resource input. Major measures include consolidating existing resources, increasing pure technical utilization efficiency, and realizing high efficient and fully use of marine sci-tech input resources. It should be noted that when the scale efficiency is relatively low, we can not realize marine sci-tech innovation solely depending on or blindly expanding scale efficiency, which will result in waste of marine sci-tech input resources. Finally, in regions with the lowest marine sci-tech input-output efficiency, it is recommended to stress the improvement of marine sci-tech management level, management technologies, and scale effect, and increase the technical progress input. Major measures include energetically cultivating innovative talents, learning and drawing lessons from excellent management level and technologies, encouraging and supporting cooperation of industry, university, and research, to make them become important means for marine sci-tech innovation system, and strengthening communication and cooperation between provinces to realize complementary advantages and common development. In sum, these measures will have excellent reference function for Guangdong Province in developing marine sci-tech innovation.

(ii) Guangdong Province should constantly improve the pure technical efficiency to keep high total factor productivity, namely, the marine sci-tech innovation ability. Major measures include bringing into full play functions of economic lever in marine sci-tech resource utilization and economic benefit coordination, promoting application and extension of marine sci-tech achievements and advanced management in marine resource utilization and marine ecological and environmental protection, consolidating existing marine resource elements to gradually realize optimal combination of marine sci-tech resource allocation, and increase marine sci-tech resource utilization in the whole province.

(iii) Guangdong Province should change the traditional marine sci-tech resource utilization ideas and energetically advocate high sci-tech oriented blue economy, so as to put an end to the situation of low contribution rate of marine sci-tech innovation to marine economy and relatively low proportion of marine new and high technical industry in marine economy. Major measures are as follows. Firstly, it is recommended to strengthen technical progress to promote high efficient, rapid and healthy development of marine sci-tech innovation in pilot regions. For example, it may increase marine sci-tech input in marine economy integrated pilot regions, expand channels of marine scientific research funds, jointly tackle key projects of marine economic development in pilot regions, attach great importance to research and development and application of marine high technologies, and expand research fields of marine economy through enhancing fundamental researches, to promote depth and scope of marine researches [21]. Secondly, pilot regions should take current situations of their marine sci-tech development, formulate specific measures in accordance with local situations, bring into full play advantages of marine sci-tech input, marine sci-tech output, and marine sci-tech efficiency in promoting marine sci-tech innovation ability, and accelerate promoting coordinated development of integrated marine economy and overall level of marine sci-tech innovation, so as to narrow the gap with provinces having higher marine sci-tech innovation input-output efficiency. Thirdly, it is recommended to speed up forming the scale effect of marine sci-tech innovation. In order to raise technical efficiency of marine sci-tech innovation, pilot regions should accelerate promote scale of marine sci-tech development, form the scale benefit of marine leading industries, and gradually put an end to the situation of low marine sci-tech efficiency and obstruction to further improvement of marine sci-tech innovation ability due to small marine sci-tech development scale.

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(To page 50)

will be charged at the rate of 1.2 times of normal water price; for water consumption exceeding the quota by over 20%, the exceeded part will be charged at the rate of 1.5-2 times of normal water price.

(iv) With the improvement of farmers' income level, water price standard can be adjusted constantly until the water supply cost can be compensated. At the same time, government subsidies can be reduced gradually until being canceled.

6 Conclusions

We should build up and enhance the awareness of water-saving, and promote the agricultural water charge collection system oriented by the increase of agricultural productivity. By means of irrigation water charge collection, enhance the farmers' sense of participation and responsibility to encourage their active participation in the management and maintenance of water conservancy projects. Set up a reasonable agricultural water price sharing system and improve the agricultural water price formation mechanism to make them scientific and reasonable with strong operability. A rational system established is not only affordable for the farmers, but can also ensure the positive operation of irrigation projects. Moreover, it can be applied to promote water conservation, develop water-saving agriculture rapidly, ensure optimal configuration and rational utilization of agricultural resources, and guarantee our national food security.

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(From page 46)

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