Production Efficiency Change and Convergence Analysis of Japonica Rice in China

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Abstract Using DEA - Malmquist index method, we perform an empirical analysis of Japonica rice production input - output panel data in 12 China's major Japonica rice producing areas during 2001 -2012, calculate the total factor input - output efficiency of China's major Japonica rice producing areas, and analyze TFP change and convergence of Japonica rice. It is found that from 2001 to 2012, the average growth rate of total factor productivity (TFP) was -2.3% and the technological progress was -2.2%, and the decline of technical progress was the main cause of the decrease of TFP. Moreover, significant differences exist between the TFP of these provinces, and the TFP of Heilongjiang and Jiangsu is higher than that of other provinces. Further convergence test indicates that TFP of the main producing areas shows σ convergence trend.

Key words Japonica rice, Malmquist index, Production efficiency, Convergence

1 Introduction

China is the world's largest rice producer and consumer, and rice is important to Chinese residents. In 2012, the national rice production accounted for 37.9% of grain production, and the sown area of rice accounted for 32.5% of that of grain. Especially since 2001, the sown area and yield of Japonica rice in China has been increasing. According to the statistics of National Grain and Oil Information Center, the sown area of Japonica rice was 8560000 ha in 2012, accounting for 28.4% of total sown area of rice, an increase of 1770000 ha over 2001; the Japonica rice production was 64440000 t in 2012, accounting for 31.6% of total rice production, an increase of 18100000 t over 2001. The study of Huang Jikun *et al.* [1] (1996) shows that for every 10% increase in income, rice demand will increase by 1.38%, while consumption of indica rice will drop by 1.16%. In recent years, Jiangsu, Zhejiang and Anhui have shown a trend of gradually changing from indica rice to Japonica rice. In this context, to ensure the growth of Japonica rice production, increasing the production efficiency and comprehensive production capacity of Japonica rice is essential to meeting Chinese residents' needs for food. Therefore, it is necessary to probe into the rice productivity growth and change in major Japonica rice producing areas, analyze the main factors leading to Japonica rice productivity change, and make horizontal comparison of differences between provinces, in order to promote rice production growth, improve the production efficiency of Japonica rice and transform the growth pattern of Japonica rice. In recent years, scholars at home and abroad have conducted a lot of researches on the issues concerning agricultural production efficiency from different angles. Meng Lingjie[2] and Fang Hong[3] measure the agricultural production efficiency of in China's different provinces. Xing Xiaojun *et al.* [4] select 8 samples and use Malmquist-DEA model to conduct a comparative study of agricultural production efficiency. Wu Fengying *et al.* [5] select the Chinese mainland and Taiwan data to perform a comparative study of agricultural TFP growth and differences on both sides of the straits. Bassam Aldeseit[6] measures the scale efficiency of 120 cow farmers by DEA in Jordan. Some scholars make typical studies on rice. By Malmquist index and regression analysis methods, Kuga[7] analyzes the influence of sixth industries on rice farmers in Japan. Yamamoto *et al.* [8] analyze the rice production efficiency change in Japan. Wang Mingli *et al.* [9] study the early indica rice, middle indica rice, late indica rice and Japonica rice in China from productivity growth, technological progress and technical efficiency. Zhang Yuejie *et al.* [10] use non-parametric HMB index to conduct an empirical analysis of rice production efficiency in eight counties (cities) of Jilin Province during 1994 -2005. Chen Chao *et al.* [11] use non-radial SBM model to study the dynamic changes in China's rice production efficiency. Xu Lijun *et al.* [12] analyze the trends and characteristics of rice production efficiency in six double harvest rice producing provinces in South China during 1995 -2010. However, the studies on the production efficiency of major Japonica rice provinces are still not perfect, so this paper uses DEA-Malmquist index method to study the production efficiency of Japonica rice in 12 main Japonica rice producing provinces during 2001 - 2012 and analyze the total factor change of Japonica rice in main Japonica rice producing provinces as well as interprovincial convergence.

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2 Research methods and indicator selection

2.1 Research methods The Malmquist Index (MI) is a bilat-

eral index, developed in 1953, can be used to compare the production technology of two economies. It is named after Professor Sten Malmquist, on whose ideas it is based. It is also called the Malmquist Productivity Index. The MI is based on the concept of the Production function. This is a function of maximum possible production, with respect to a set of inputs pertaining to capital and labor. In 1982, Cave[13] and Fare applied it to the production theory for estimating the change in production efficiency. Based on DEA, Fare *et al.* change Malmquist productivity index from theoretical index to empirical index. In 1994, Fare *et al.*[14] further decomposed Malmquist index into changes in technical efficiency, technological progress and scale efficiency. Similarly, in this article, we can decompose the reasons for rice TFP change into technological progress and technical efficiency changes, and technical efficiency change can be further decomposed into pure technical efficiency and scale efficiency changes. Based on total factor input, Malmquist index can be expressed as:

$$M_i^{t+1} = \frac{D_i^{t+1}(x^t, y^t)}{D_i^{t+1}(x^{t+1}, y^{t+1})}$$

By the two Malmquist indices under technical conditions in different periods, we take their geometric mean, which can be expressed as:

$$M_i = TFP = (x^{t+1}, y^{t+1}, x^t, y^t)$$
$$= \sqrt{\frac{D_i^{t+1}(x^t, y^t)}{D_i^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_i^{t}(x^t, y^t)}{D_i^{t}(x^{t+1}, y^{t+1})}}$$
$$= \frac{D_i^{t}(x^t, y^t)}{D_i^{t+1}(x^{t+1}, y^{t+1})} \sqrt{\frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^{t}(x^{t+1}, y^{t+1})} \times \frac{D_i^{t+1}(x^t, y^t)}{D_i^{t}(x^t, y^t)}}$$

It can also be expressed as:

$$TFP = Effch \times Tech$$

where *Effch* is the relative efficiency change index, which can be further decomposed into pure efficiency (*Pech*) change and scale efficiency (Sech) change; Tech is the production technological change from period t to $t+1$, an indicator representing the extent of technological progress and innovation.

The above formula can be expressed as:

$$TFP = Effch \times Tech = (Pech \times Sech) \times Tech.$$

When $TFP = 1$, it indicates that productivity does not change; when $TFP > 1$, it indicates that productivity makes progress; when $TFP < 1$, it indicates that productivity lags behind.

2.2 Sample selection and data sources In this paper, data are from *National Agricultural Cost-Benefit Data Compilation* and *China Statistical Yearbook*. We select 12 Japonica rice producing provinces and autonomous regions (Hebei, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Shandong, Henan, Hubei, Yunnan and Ningxia) during 2001 – 2012, select the main product output of Japonica rice per mu in the 12 provinces and autonomous regions as output indicator, select fertilizer costs, pesticide costs, machinery and animal power costs, other direct material costs labor input as input indicators. To eliminate the impact of the price, various cost indicators are deflated in accordance with various production material price indices provided by *China Statistical Yearbook*. The upper half of Table 1 shows the average rice input and output in 12 Japonica rice producing provinces and autonomous regions during 2001 – 2012, and the lower half of Table 1 shows the average Japonica rice production input and output in 12 Japonica rice producing provinces and autonomous regions during 2001 – 2012. As can be seen from Table 1, the rice yield showed an overall upward trend from 2001 to 2012 except a slight fall in individual years. From the rice input factors, pesticide costs, machinery and animal power costs underwent great changes, while fertilizer costs and other material costs underwent small changes. In this period, pesticide costs increased by 2.6 times; machinery and animal power costs went through the greatest change, from 44.8 yuan in 2001 to 143.5 yuan in 2012; machinery costs significantly increased while animal power costs presented a downward trend, due to the fact that agricultural machinery has replaced more manual labor in recent years; the labor input decreased from 14.6 days per mu in 2001 to 6.5 days per mu in 2010; fertilizer costs fluctuated between 70 and 80 yuan per mu, and the changes in other material costs were not obvious. From the lower half, it can be found that there is a great difference in the Japonica rice yield between various regions, and the yield is highest in Ningxia and Hebei, reaching 573 kg per mu, while the yield is lowest in Hubei, reaching only 415 kg per mu. There is also a great difference in the factor input level between various regions, and the fertilizer costs are highest in Shandong, reaching 169 yuan per mu while the fertilizer costs are lowest in Hubei, only 70 yuan. In addition, there is a significant difference in the pesticide costs, and the pesticide costs are highest in Zhejiang, reaching 82 yuan per mu, while the pesticide costs reach only 16 yuan per mu in Jilin. Compared with Jiangsu and Zhejiang, Northeast seldom has rice pests and diseases, so the pesticide costs are naturally low. We also find that the machinery and animal power costs are high in Zhejiang and Heilongjiang, while the labor input is low, which indicates that agricultural machinery in Zhejiang and Heilongjiang has replaced part of the manual labor.

3 Empirical analysis

3.1 Malmquist TFP index and decomposition Based on the input-output data about 12 Japonica rice producing provinces or autonomous regions during 2001 – 2012, we use the Malmquist index method and DEAP2.1 software for calculation to get the change in the production efficiency of Japonica rice in the 12 areas (Table 2). The average total factor production efficiency index change during 2001 – 2012 and the decomposition results are shown in Table 3. As can be seen from the results in Table 2, for the 12 Japonica rice producing provinces or autonomous regions during 2001 – 2012, only Heilongjiang and Zhejiang had Tfpch of greater than 1, indicating that the average annual total factor productivity index in the two provinces continued to increase; the other 10 provinces had Tfpch of smaller than 1, indicating that the average annual total factor productivity index in the 10 provinces decreased. TFP was highest in Heilongjiang, reaching 1.014, while TFP was lowest in Ningxia, reaching 0.935. In terms of the

technological progress change index of Japonica rice, it was greater than 1 in Heilongjiang and Zhejiang, it was less than 1 in the other 10 provinces, and it was lowest in Ningxia. During 2001 – 2012, the production technology made some progress only in Heilongjiang and Zhejiang, and the technological progress showed a downward trend in the process of Japonica rice production in other provinces. Except Liaoning and Anhui, TFP index change was consistent with technological progress change in the other 10 provinces, that is to say, the technological progress of these provinces determined the TFP index. The pure technical efficiency, scale efficiency and technological progress declined in Liaoning and Anhui. In terms of the scale efficiency change index, it declined slightly in Hebei, Liaoning and Anhui, while it did not change in the other 9 provinces, suggesting that the scale efficiency of Japonica rice has not been improved in recent years, and it declined in 3 provinces. Pure technical efficiency only rose in Hebei, and it lowered in Anhui and Liaoning, but remained unchanged in the other nine provinces. Table 3 shows the TFP index change and decomposition in China's major Japonica rice producing provinces during 2001 – 2012. From the time series, it rose in 2001 – 2002, 2003 – 2004, 2008 – 2009 and 2010 – 2011, but lowered in other years. In general, there was a downward trend with great volatility. In terms of the technical efficiency, it showed a slight decline. From the time series, it was greater than or equal to 1 in eight years and showed a steady upward trend, and it was less than 1 in three years and showed a downward trend, but due to technological progress, it was greater than 1 and showed an upward trend in only three years, and less than 1 in eight years and showed a downward trend, thereby leading to an overall decline in TFP index. It was greater than 1 and rose in only four years, that is, the decline in TFP is mainly due to lowering technological progress. As can be seen from Fig. 1, technological progress and TFP share the similar trend, and technological progress change is a dominant factor in determining the production efficiency of Japonica rice.

Table 1 The average input and output per unit area in Japonica rice producing provinces (autonomous regions) (667 m^2)

Year Area	Yield per unit area // kg	Fertilizer costs // yuan	Pesticide costs // yuan	Machinery and animal power costs // yuan	Other material costs // yuan	Labor input person · day
2001	477.80	73.47	20.79	44.82	62.30	14.60
2002	482.40	71.61	19.84	42.84	68.45	13.50
2003	459.00	69.76	22.32	44.27	71.93	13.40
2004	507.00	76.99	29.24	57.17	62.07	10.30
2005	486.60	77.31	40.30	65.79	61.44	9.92
2006	514.50	76.87	44.02	74.68	57.08	9.30
2007	513.90	77.47	49.84	82.91	56.51	8.65
2008	529.20	80.64	52.43	92.21	59.74	8.18
2009	520.97	72.53	47.12	89.86	63.07	7.66
2010	509.27	72.86	50.12	108.46	58.69	7.02
2011	534.27	75.77	50.36	120.70	59.44	6.64
2012	547.85	74.90	54.63	143.51	59.11	6.52
Hebei	573.57	135.43	42.72	61.88	132.37	14.71
Liaoning	528.55	128.39	23.35	97.77	117.56	9.05
Jilin	496.39	97.96	16.40	89.84	87.86	8.29
Heilongjiang	474.80	75.56	17.88	97.05	84.17	5.91
Jiangsu	552.99	142.43	76.07	93.94	37.09	8.27
Zhejiang	487.73	100.26	81.66	106.89	41.26	6.32
Anhui	458.00	102.80	47.53	92.53	52.06	9.99
Shandong	528.44	169.08	45.99	58.13	88.30	10.97
Henan	450.72	135.97	38.15	50.93	65.51	13.54
Hubei	414.68	69.57	26.85	56.20	51.07	10.07
Yunnan	547.94	131.54	22.40	72.62	59.64	22.85
Ningxia	573.05	149.32	21.74	82.71	132.74	14.33

Note: *National Agricultural Cost-Benefit Data Compilation* (2002 – 2013).

Table 2 The average calculation results of Japonica rice productivity index in China

Regions	Technical efficiency change index (*Effch*)	Technological progress change index (*Techch*)	Pure technical efficiency change index (*Pech*)	Scale efficiency (*Sech*)	TFP index (*Tfpch*)
Hebei	1.000	0.971	1.004	0.996	0.971
Liaoning	0.985	0.973	0.991	0.994	0.958
Jilin	1.000	0.969	1.000	1.000	0.969
Heilongjiang	1.000	1.014	1.000	1.000	1.014
Jiangsu	1.000	0.991	1.000	1.000	0.991
Zhejiang	1.000	1.013	1.000	1.000	1.013
Anhui	0.997	0.993	0.998	0.999	0.990
Shandong	1.000	0.976	1.000	1.000	0.976
Henan	1.000	0.948	1.000	1.000	0.948
Hubei	1.000	0.990	1.000	1.000	0.990
Yunnan	1.000	0.971	1.000	1.000	0.971
Ningxia	1.000	0.935	1.000	1.000	0.935
Mean	0.999	0.978	0.999	0.999	0.977

Table 3 The annual average TFP index change and decomposition during 2001 – 2012

Regions	Technical efficiency change index (*Effch*)	Technological progress change index (*Techch*)	Pure technical efficiency change index (*Pech*)	Scale efficiency (*Sech*)	TFP index (*Tfpch*)
2001 – 2002	1.000	1.018	1.004	0.996	1.018
2002 – 2003	1.008	0.935	1.008	1.008	0.943
2003 – 2004	0.963	1.045	0.982	0.980	1.006
2004 – 2005	1.011	0.917	1.010	1.002	0.928
2005 – 2006	1.003	0.989	1.004	0.999	0.992
2006 – 2007	1.004	0.965	0.997	1.007	0.969
2007 – 2008	0.991	0.997	0.983	1.009	0.988
2008 – 2009	1.012	0.988	1.017	0.996	1.001
2009 – 2010	0.988	0.928	0.988	1.000	0.917
2010 – 2011	1.005	1.021	1.010	0.995	1.026
2011 – 2012	1.000	0.966	1.000	1.000	0.965
Mean	0.999	0.978	0.999	0.999	0.977

3.2 Interprovincial TFP convergence of Japonica rice Convergence can be divided into σ convergence and β convergence, and β convergence is divided into absolute β convergence and conditional β convergence. Another convergence type based on β convergence is called "club convergence" according to the particular convergence trend[15]. In this study, we use convergence to analyze the convergence and divergence of TFP among various Japonica rice producing provinces in China. From the above analysis results, it is found that there is a great difference in the TFP of Japonica rice between various provinces, and technology diffusion among regions can narrow technical differences between the areas and improve industrial competitiveness. Here, we use σ convergence to test whether there is convergence in the TFP of Japonica rice in China. If the difference in TFP of Japonica rice between various provinces decreases over time, it is considered that there is σ convergence. Here we use CV (coefficient of variation) of TFP of Japonica rice for analysis: $CV = SD/\bar{x}$. It can also be expressed as follows:

$$CV = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} / \bar{x}$$

where x_i is the TFP of Japonica rice in region i; $\bar{x}$ is the average TFP of Japonica rice in various provinces.

The larger the value of CV, the greater the difference in the TFP of Japonica rice. If CV decreases, it indicates that there is σ convergence in the TFP of Japonica rice. The calculated values are shown in Fig. 2, and overall the coefficient of variation decreases, indicating that China's Japonica rice production has σ convergence features, and there is technical diffusion among different provinces. The coefficient of variation was largest in 2003, and it showed a narrowing trend during 2004 – 2009 except 2007, that is, the gap between 12 main Japonica rice producing provinces was narrowed; the fluctuation during 2010 – 2012 was larger than in previous period, indicating that the gap between the main rice producing provinces during 2010 – 2012 was greater than during 2004 – 2009.

4 Conclusions and recommendations

4.1 Conclusions Using DEA – Malmquist index method, we perform an empirical analysis of Japonica rice production input – output panel data in 12 China's major Japonica rice producing areas during 2001 – 2012, calculate the total factor input – output efficiency of China's major Japonica rice producing areas, and analyze TFP change and convergence of Japonica rice. It is found that from 2001 to 2012, the average growth rate of total factor productivity (TFP) was – 2.3% and the technological progress was – 2.2%, and the decline of technical progress was the main cause of the decrease of TFP. Moreover, significant differences exist between the TFP of these provinces, and the TFP of Heilongjiang and Jiangsu is higher than that of other provinces. Further convergence test indicates that TFP of the main producing are-

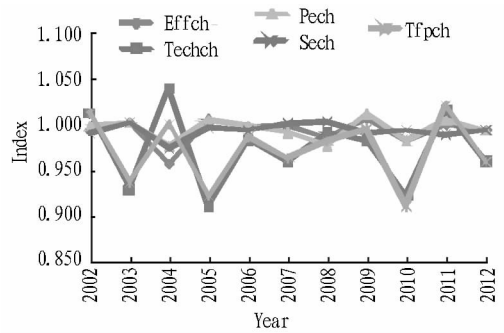

Fig. 1 The annual average TFP index change and decomposition during 2001 – 2012

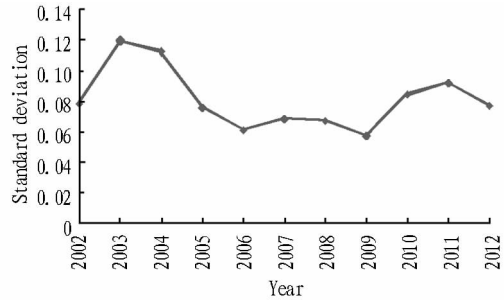

Fig. 2 The standard deviation change in rice TFP of China's major Japonica rice producing provinces during 2002 – 2012

as shows σ convergence trend.

4.2 Recommendations(i) In terms of the production efficiency of Japonica rice in 12 provinces, there are some differences between various regions, and TFP change is basically consistent with technological progress trend. The technical efficiency change index is less than 1 and shows a downward trend in Liaoning and Anhui but is equal to 1 in other provinces, indicating that the technical efficiency of the two provinces should be improved and the resource allocation efficiency is poor. In addition, the pure technical efficiency index is 1.004 in Hebei, but the scale efficiency index shows the same downward trend like Liaoning and Anhui, so it is necessary to vigorously promote large-scale production of rice and improve scale efficiency. (ii) The TFP index of Japonica rice in China underwent great volatility during 2001 – 2012, and it showed an overall downward trend. And TFP fluctuations were most significantly affected by technological progress change and also affected by pure technical efficiency and scale efficiency. It is necessary to enhance scientific and technological development, improve the technological content of Japonica rice production, actively promote the popularization and innovation of agricultural science and technology, strengthen breeding and improve varieties, and use policies to guide farmers to make use of scientific and technological achievements. (iii) The change in technological progress is the main factor responsible for TFP change of Japonica rice. In the future, it is necessary to increase research, development and promotion of agricultural technology, increase conversion rate of scientific achievement, actively train farmers to have the ability to master new technology, and strengthen technological innovation for Japonica rice production. (iv) It is necessary to help farmers to rationally allocate the input factors for Japonica rice production, and improve the contribution of pure technical efficiency to Japonica rice TFP. At the same time, based on the actual local conditions, the local government should actively encourage land transfer, develop appropriate scale operation, and increase intensive and professional level of farmland, in order to improve the contribution of scale efficiency of rice to TFP change of Japonica rice. (v) There are significant differences in TFP between the rice producing provinces, but in terms of interprovincial convergence, the TFP in major Japonica rice producing areas shows σ convergence, indicating that with economic development, the regional difference is narrowing toward a balanced level of development. In the future, based on natural endowments, various provinces should strengthen macro-control and take different measures to improve the production efficiency of Japonica rice and improve the overall competitiveness of China's Japonica rice industry.

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