A research on the efficiency of regional green innovation in China—Based on DEA-SBM model and Malmquist index method

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Abstract: This paper selects panel data of 29 provinces in mainland China from 2010-2017 and combines a DEA-SBM model that takes into account non-desired outputs and the Malmquist index method to study the static and dynamic changes of regional green innovation efficiency. It is found that the overall level of green innovation efficiency in China is low, but the overall trend is on the rise and there is more room for improvement. The differences in green innovation efficiency values among the three regions of East, West and Central Asia are obvious, with the eastern region developing at a higher level than the central and western regions, and the gap is gradually narrowing. Technological progress is a key factor affecting total factor productivity.

1 Introduction

With the coming of the "3.0 era of globalization", Chinese economic development level has reached a higher level, and it is also facing more challenges. On the one hand, development has entered a new normal, with the economic growth rate shifting from high speed to medium speed and slowing down, indicating that the influence of the old driving force of Chinese economic growth is gradually weakening, the momentum of the new driving force has not yet taken off, and the transformation and upgrading of economic development is slow. On the other hand, after entering the 21st century, the sloppy economic development model still exists, which brings a series of costs such as serious environmental pollution and high waste of resources. In this context, China's 13th Five-Year Plan puts forward the five major development concepts of "innovation, coordination, green, openness and sharing", and the report of the 19th National Congress also points out that the new development concept should be firmly implemented and the vitality of development and innovation of the whole society should be enhanced. Therefore, the strategic integration of green development and innovation development will certainly inject new vitality into the development of Chinese economy. This research constructs a DEA-SBM model to calculate regional green innovation efficiency considering non-desired output, and through analyzing regional differences, suggests suggestions for improving regional

green innovation efficiency and achieving sustainable social development in China.

2 Model construction, indicator system and data sources

2.1. Non-radial DEA-SBM model

Data Envelopment Analysis (DEA) does not require a pre-designed multi-input, multi-output production function, which avoids the risk of unreasonable function design while also simplifying the workload and enabling more objective measurement results to be obtained. The SBM model proposed by Tone in 2001, which puts slack variables into the objective function, considers the case of inefficiency based on a non-radial perspective and can solve the problem of non-expected output that may arise in the innovation process of industrial enterprises. The specific formula is as follows.

Assume n decision units, m inputs, element $x \in R^m$, defined $X \in (x_1, x_2 \dots x_n) \in R^{m \times n}$ and $x_i > 0$; there are s outputs, including s_1 desired output and element $y^g \in R^{s_1}$, s_2 non-desired output and element $y^b \in R^{s_2}$, defined:

$$Y^g = (y_1^g, y_2^g \dots y_n^g) \in R^{s_1 \times n} (1)$$

$$Y^b = (y_1^b, y_2^b \dots y_n^b) \in R^{s_2 \times n} (2)$$

Also $y_i^g > 0$, $y_i^b > 0$, so DEA—SBM model can be:

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$$\rho^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2} \left\{ \sum_{i=1}^{s_1} \frac{s_i^g}{y_{i0}^g} + \sum_{i=1}^{s_2} \frac{s_i^b}{y_{i0}^b} \right\}}$$

$$\begin{aligned} s.t. & x_0 = X\lambda + s^- \\ & y_0^g = Y^g\lambda - s^g \\ & y_0^b = Y^b\lambda + s^b \\ & \lambda \geq 0, s^- \geq 0, s^g \geq 0, s^b \geq 0 \end{aligned} \quad (3)$$

Among them, s^- , s^g , s^b are slack variables for inputs, desired outputs, and non-desired outputs, respectively. The objective function is strictly decreasing with respect to the variables s^- , s^g , s^b and the objective function value $\rho^* \in [0, 1]$. When $\rho^* = 1$, s^- , s^g , s^b all are 0, indicating that the decision unit is valid; when $\rho^* < 1$, indicating that the decision unit is invalid.

2.2. Evaluation index system

Based on the existing literature, this research divides the regional green innovation efficiency evaluation indicators into input indicators, expected output indicators and non-expected ones. Inputs generally include human inputs and financial inputs. In this paper, the full-time equivalent amount of R&D personnel, which can reflect the amount of human inputs and actual working hours of personnel in innovation activities, is selected as the human input indicator, and the internal expenditure of R&D funds, which can reflect the actual expenditure in innovation activities, is selected as the financial input indicator. For the desired output, it will be divided into innovation benefit output and economic benefit output. The number of patents granted for inventions, which can reflect the innovation development capability of the region, is selected to measure innovation benefit output, and the turnover of technology market contracts, which can reflect the degree of transformation of scientific and technological achievements, is selected to measure economic benefit output. At the level of non-desired outputs of innovation activities, three indicators, namely industrial wastewater emissions, industrial sulphur dioxide emissions and industrial solid waste emissions, were selected to evaluate the environmental benefits. Details are shown in Table 1.

Table 1 green innovation efficiency index system

Tier 1 Indicators	Classification of indicators	Secondary indicators
Input Indicators	Human Inputs	R&D personnel full time equivalent
	Financial Inputs	Internal expenditure on R&D funding
Desired Output Indicators	Innovation efficiency output	Number of Invention Patents Granted

	Economic output	Technology market contract turnover
Non-desired output indicators	Environmental Pollutant Outputs	Industrial wastewater emissions
		Industrial sulphur dioxide emissions
		Industrial solid waste emissions

2.3. Data sources

In this research paper, 29 provincial-level administrative regions in China are selected (Hong Kong, Macao, Taiwan, Qinghai and Tibet are not included due to limited data), and the data are mainly obtained from China Statistical Yearbook, China Science and Technology Statistical Yearbook and China Environmental Statistical Yearbook in previous years.

3 Empirical Results and Analysis

3.1. Static analysis of regional green innovation efficiency

Based on the DEA-SBM model and the green innovation efficiency evaluation index system, the measured results are shown in Table 2, the regional green innovation efficiency values of China can be analyzed from the following 2 perspectives.

From a national perspective as a whole, the overall regional green innovation efficiency value of the country as a whole did not change much from 2010 to 2017, except for 2010, which fluctuated between 0.27 and 0.28, a relatively small value, indicating that there is still much room for improvement in terms of regional green innovation in China. In addition, among the 29 provinces and cities selected for this paper, the top ten provinces and cities in terms of average green innovation efficiency values include five in the east, two in the centre and three in the west, with Beijing and Hainan in the east reaching the efficiency frontier in terms of efficiency values; while among the bottom five provinces and cities, one in the east, one in the centre and three in the west.

It can be seen that green innovation efficiency among the provinces and cities in China shows a large difference, with the provinces and cities in the eastern region having a somewhat higher level of green innovation compared to the provinces and cities in the central and western regions.

Looking at the three major regions of the east, central and west, on the one hand, the national average value of regional green innovation efficiency is 0.28, while that of the eastern region is 0.35, that of the central region is 0.22 and that of the western region is 0.25. It can thus be seen that the regional green innovation efficiency value of the eastern region of China is much higher than the

national average, while the efficiency values of the central and western regions are lower than the national average, which indicates that the development of green innovation and economic development This indicates that the development of green innovation is basically in line with the pace of economic development, with the eastern region paying great attention to the investment in science and technology innovation activities and environmental protection while the rapid economic

development, and the innovation resource allocation mechanism is working well, while the central and western regions have a weaker innovation foundation and less innovation investment. On the other hand, the gap between the regional green innovation efficiency values in the East, Central and Western regions shows a trend of gradual reduction, which indicates that in recent years, the Central and Western regions are also further promoting the development of innovation undertakings.

Table 2 Regional green innovation efficiency values in China, 2010-2017

	2010	2011	2012	2013	2014	2015	2016	2017	average
Beijing	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tianjin	0.33	0.28	0.27	0.24	0.22	0.21	0.22	0.24	0.25
Hebin	0.13	0.13	0.13	0.11	0.09	0.10	0.12	0.13	0.12
Liaoning	0.29	0.28	0.30	0.24	0.24	0.33	0.32	0.31	0.29
Shandong	0.16	0.15	0.14	0.15	0.16	0.17	0.18	0.17	0.16
Shanghai	0.65	0.50	0.48	0.42	0.40	0.39	0.38	0.34	0.45
Jiangsu	0.23	0.24	0.24	0.24	0.23	0.24	0.23	0.22	0.23
Zhejiang	0.17	0.16	0.14	0.12	0.11	0.11	0.16	0.19	0.15
Fujian	0.17	0.15	0.16	0.13	0.11	0.13	0.10	0.13	0.13
Guangdong	1.00	0.31	0.26	0.27	0.22	0.25	0.25	0.25	0.35
Hainan	1.00	1.00	1.00	1.00	1.00	0.13	0.13	0.13	0.67
Shanxi	0.17	0.17	0.17	0.19	0.20	0.24	0.20	0.22	0.20
Heilongjiang	0.30	0.30	0.33	0.30	0.32	0.37	0.39	0.41	0.34
Jilin	0.21	0.23	0.19	0.21	0.16	0.15	0.26	0.36	0.22
Anhui	0.19	0.21	0.20	0.24	0.26	0.33	0.30	0.27	0.25
Jiangxi	0.14	0.18	0.18	0.16	0.16	0.16	0.15	0.14	0.16
Henan	0.13	0.14	0.12	0.11	0.10	0.10	0.10	0.11	0.11
Hubei	0.23	0.24	0.25	0.26	0.27	0.31	0.31	0.31	0.27
Hunan	0.22	0.17	0.15	0.19	0.20	0.20	0.17	0.19	0.19
Shanxi	0.28	0.38	0.39	0.38	0.40	0.40	0.39	0.40	0.38
Gansu	0.27	0.31	0.29	0.32	0.29	0.31	0.31	0.32	0.30
Ningxia	0.09	0.15	0.12	0.08	0.12	0.13	0.13	0.15	0.12
Xinjiang	0.14	0.13	0.14	0.08	0.08	0.07	0.08	0.10	0.10
Sichuan	0.21	0.24	0.25	0.26	0.28	0.31	0.29	0.28	0.26
Chongqing	0.38	0.36	0.29	0.31	0.29	0.20	0.26	0.14	0.28
Yunnan	0.27	0.25	0.37	0.33	0.32	0.25	0.22	0.20	0.28
Guizhou	0.28	0.30	0.20	0.26	0.30	0.27	0.24	0.29	0.27
Guangxi	0.08	0.08	0.04	0.08	0.12	1.00	1.00	1.00	0.43
Inner Mongolia	0.14	0.12	0.23	0.12	0.07	0.08	0.06	0.08	0.11
East	0.47	0.38	0.37	0.36	0.34	0.28	0.28	0.28	0.35
central	0.20	0.21	0.20	0.21	0.21	0.23	0.24	0.25	0.22
West	0.21	0.23	0.23	0.22	0.23	0.30	0.30	0.30	0.25
Whole China	0.31	0.28	0.28	0.27	0.27	0.27	0.27	0.28	0.28

3.2. Dynamic analysis of regional green innovation efficiency

This research also conducts a dynamic analysis of efficiency values by measuring and decomposing the Malmquist index of regional green innovation efficiency from 2010-2017 to reflect the role played by technological progress and technical efficiency on innovation efficiency, as detailed in Table 3 and Figure 1.

Overall, the Malmquist index is greater than 1 for all provinces, which indicates that the overall green innovation efficiency of each province in China is on an increasing trend and the level of green innovation is improving. After decomposing the ML index, it can be

found that 11 provinces have a technical efficiency (EC) less than 1 and all provinces have a technological progress (TC) greater than 1. This indicates that although the level of green innovation in China is increasing, the input and output structure is still not perfect. From the trends of MI, TC and EC in Figure 1, it can be seen that the trends of technological progress and total factor productivity are basically consistent, and from the two time periods of 2012-2013 and 2015-2016, it can be seen that the increase in technical efficiency has not offset the impact of the decline in technological progress, indicating that technological progress is a key factor affecting total factor productivity, which is consistent with the regional analysis of results. In addition, the ML index has been roughly on a downward trend in recent

years, which indicates that the momentum of green innovation development in China is insufficient at this stage and the growth rate has declined.

Looking at the eastern, central and western regions, their ML indices are 1.34, 1.24 and 1.17 respectively, featuring a stepwise distribution decreasing from the east to the central and western regions. It indicates that the

eastern region, with its superior economic advantages, surpasses the central and western regions in the development of green innovation undertakings, while the central and western regions, especially the western regions, are still lagging behind in terms of economic foundation, industrial base and science and technology innovation level.

Table 3 Malmquist index of China's regional green innovation efficiency and its decomposition

Region	MI	EC	TC	Region	MI	EC	TC	Region	MI	EC	TC
Beijing	1.21	1.00	1.21	Shanxi	1.15	1.04	1.11	Shanxi	1.17	1.05	1.11
Tianjin	1.08	0.96	1.12	Heilongjiang	1.56	1.26	1.24	Gansu	1.13	1.03	1.10
Hebin	1.11	1.01	1.10	Jilin	1.24	1.12	1.11	Ningxia	1.23	1.12	1.10
Liaoning	1.15	1.02	1.13	Anhui	1.55	1.27	1.22	Xinjiang	1.06	0.97	1.09
Shanghai	1.24	0.92	1.35	Jiangxi	1.12	1.00	1.12	Sichuan	1.16	1.04	1.12
Jiangsu	1.26	0.99	1.27	Henan	1.08	0.98	1.10	Chongqing	1.02	0.90	1.13
Zhejiang	1.47	1.04	1.41	Hubei	1.18	1.05	1.12	Yunnan	1.14	0.98	1.16
Fujian	1.07	0.97	1.10	Hunan	1.10	0.99	1.11	Guizhou	1.32	1.03	1.28
Shandong	1.13	1.01	1.12					Guangxi	1.44	1.20	1.20
Guangdong	1.41	0.88	1.60					Inner Mongolia	1.12	1.00	1.12
Hainan	2.46	0.88	2.79								
East	1.34	0.97	1.38	central	1.24	1.09	1.14	West	1.17	1.03	1.14

Note: EC means efficiency change, TC means technological change and MI means productivity index.

Figure 1 Malmquist index of regional green innovation efficiency in China and its decomposition variation

4 Conclusions and Recommendations

4.1 Conclusion

By analyzing the green innovation efficiency of 29 inter-provincial regions in China from 2010-2017, this research obtains the following conclusions:

1. Chinese regional green innovation efficiency levels are low, and there are still certain phenomena such as poor resource utilization and environmental pollution, and there is greater room for improvement. In addition, the uneven development between provinces is remarkable, with Beijing, Hainan and Shanghai having the highest efficiency values, and Inner Mongolia, Henan and Xinjiang having the lowest efficiency values, and the difference is large.

2. Regional differences in green innovation efficiency are obvious, with the three major regions showing a trend of "East > West > Central", and the green innovation efficiency value of the eastern region is much higher than the national average. This indicates that the eastern region has a good development trend in science and technology innovation, the western region has a

greater development potential by virtue of China's western development and ecological civilization construction policies, and the central region has a greater pressure of industrial transformation. In addition, the gap between the regional green innovation efficiency values of the eastern, central and western regions has been gradually narrowing in recent years, indicating to a certain extent that the central and western regions are also further strengthening their support for science and technology innovation activities.

3. Analysis of the Malmquist Index reveals that the ML indexes of all 29 provinces and regions are greater than 1, showing a trend of East > Central > West, which indicates that Chinese green innovation efficiency as a whole is on a growth trend and the growth rate has regional differences. Further decomposition of the ML index reveals that the change trend of total factor productivity and the change trend of technological progress basically remain the same, indicating that technological progress is the key factor affecting total factor productivity. In addition, the ML index has shown a decreasing trend in recent years, indicating that the development momentum of green innovation is insufficient at this stage, and it is necessary to improve the efficiency of innovation resource allocation and pay attention to environmental protection.

4.2 Policy recommendations

Based on the above conclusions, this research puts forward the following policy recommendations:

1. Coordinate the development mechanism of regional green innovation efficiency. Because of the obvious regional differences in China's green innovation efficiency, the government should adopt a targeted differentiated strategy. The eastern region should make full use of its technological base and location advantage to introduce advanced foreign green technologies and improve the transformation rate of technological

achievements; the central region has a large proportion of traditional industries with high energy consumption and pollution, and should accelerate the transformation and upgrading of industrial green production through environmental taxation and other means, strengthen cooperation with research institutions and higher education institutions, formulate innovation and entrepreneurship policies, and The western region is developing well and should continue to adhere to the policy of western development and ecological and environmental protection, and use energy projects to form cooperation with the eastern and central regions to achieve synergistic development.

2. Adhere to the sustainable development strategy and environmental protection, improve the legal system, increasing the enforcement of environmental protection departments, and actively implement the development concept of innovation, coordination, green, development and sharing to achieve coordinated development of economic development and environmental protection.

3. Improve the openness of the regions. The eastern regions relying on coastal advantages and the central and western regions seizing the opportunity of the "Belt and Road" construction to introduce advanced innovative technologies and promote industrial transformation.

Acknowledgments

This research is one of the milestones of the National Innovation and Entrepreneurship Training Program for college student (202010497016)

References

1. Han J. (2012) Research on the efficiency of regional green innovation in China [J]. Research on Finance and Economics, 2012(11): 130-137.
2. Liang W, Qin T, Liang P. (2019) Classification and Comparison of Regional Green and Low Carbon Innovation Efficiency in China [J]. Arid Zone Resources and Environment ,33(11):9-16.
3. Zhu h, Zhang M. (2019) Construction and empirical evidence of green development evaluation index system [J]. Statistics and decision making, 35(17):36-39.
4. Xiao R, Ding J, Qian L. (2017) Review of research on green innovation performance evaluation [J]. Journal of Guizhou University of Finance and Economics, 2017(2):100-110.
5. Yin Q, Cheng Y. (2016) Research on Regional Variability and Causes of Green Innovation Efficiency in China [J]. Jiangsu Social Science, 2016(2):64-69.
6. Liang S, Luo L. (2019) The dynamic effect of international R&D capital technology spillover on the efficiency of green technology innovation [J]. Scientific Research Management, 40(3): 21-29.