Measurement and Analysis of Green Harnessing Efficiency of the Yellow River Basin
——Based on Super-Efficiency DEA and Malmquist Index

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ABSTRACT

The meaning of green governance can effectively resolve the problems that lead to unbalanced and insufficient development and make green governance a feasible way to achieve a better life for the people. Based on the connotation and characteristics of green governance, this paper constructs a green governance efficiency evaluation index system from two dimensions of input and output; This paper measures and analyzes the green governance efficiency of provinces and cities in the Yellow River Basin based on the super-efficiency DEA and Malmquist index. The research found that the efficiency of green governance in the provinces and cities of the Yellow River Basin in China presents the typical characteristics of small intra-regional gaps and large cross-regional gaps. The green governance efficiency of the provinces and cities in the Yellow River Basin is on the rise, and the increase in green governance efficiency is mainly due to changes in the rate of technological progress, which fully demonstrates that whether the government can support and carry out effective technological investment and innovation is an important constraint affecting the improvement of green governance efficiency. From the perspective of the average change of each year, the green governance efficiency of the provinces and cities in the Yellow River Basin has shown a tortuous and fluctuating trend.

Keywords: *Yellow River Basin; green governance efficiency; super-efficiency DEA; Malmquist index*

1. INTRODUCTION

With the rich connotation of green governance, the problems that lead to unbalanced and insufficient development can be effectively resolved, and green governance can be a feasible way to achieve a better life for the people. Green governance refers to the activity process of a diverse green governance subject guided by the concept of green values to achieve sustainable and harmonious development and a good life, and in this process to promote the overall development of people. Green governance requires the consideration and solution of governance issues into the political environment, economic environment, social environment, cultural environment, ecological environment, and the interaction between governance entities. The goal of green governance is to continuously satisfy the people's yearning for a better life and achieve the goal of a better life for the people with high quality. To determine whether green governance can achieve a

better life, it is necessary to establish an evaluation system for green governance capabilities. Green governance efficiency is an important yardstick to measure the rational allocation of regional green governance resources and the construction of green governance capabilities, and it has important practical significance to carry it out.

The green and high-quality development of the Yellow River Basin is related to the country's comprehensive promotion of the high-quality development process. According to the instructions of the "Outline of the Yellow River Basin Ecological Protection and High-quality Development Plan", it is necessary to adopt measures to local conditions, implement classified policies, and respect laws to improve the ecological environment of the Yellow River Basin, promote high-quality development of the entire basin, and let the Yellow River become a river of happiness for the benefit of the people. Because of this, this paper measures the efficiency of green governance in the provinces and cities of the Yellow River Basin,

which analyzes the dynamic evolution trajectory of green governance efficiency and provides a reference for improving the efficiency of green governance in the Yellow River Basin.

2. LITERATURE REVIEW

The new connotation of green governance is embodied in the pluralistic green governance subjects, contextual green governance behaviours and balanced green governance results. These diversified elements are interrelated, unified in the process of green governance, and constitute the basic model of the green governance system.

Green innovation efficiency evaluation and green development evaluation have always been the focus of researchers. Yang Lisheng et al. (2018) used the undesired SBM-DEA model to build a green continuous innovation efficiency evaluation system based on the definition of the concept of corporate green continuous innovation, measured the efficiency of continuous green innovation of industrial enterprises above designated size, found that Chinese companies' green continuous innovation's efficiency is low and there is a significant regional gap in the efficiency of corporate green continuous innovation[1]. Li Jinyan et al. (2017) measured the green innovation efficiency of 12 prefecture-level cities in Hubei Province through the entropy method combined with the stochastic frontier model beyond the logarithm and analyzed the influencing factors. They believed that the input of innovation resources has a significant effect on the output of green innovation, and excessively strict environmental regulations and regional openness negatively affect green innovation[2]. Liu Mingguang (2017) used the combined DEA efficiency evaluation model to evaluate the efficiency of China's regional green innovation, analyzed the temporal and spatial characteristics of China's regional green innovation efficiency from both vertical and horizontal perspectives, and used the spatial error panel model (SEPDM) to emphasize the importance of the input structure and utilization efficiency of innovative resources[3]. With the presentation of the "five in one" overall layout and the continuous improvement of the five development concepts, scholars began to pay attention to green governance activities. Li Wei'an et al. (2017) combed the evolution of green governance, expounded the basic connotation and theoretical basis of green governance, and discussed that effective implementation of green governance requires multiple governance entities and governance mechanisms such as collaborative governance and network governance[4]. Wang Ren (2021) analyzed the micro-data of 334 public companies to assess the governance effects of China's green policies on green finance and the differences in the governance effects of different types of green policies

on green finance, and concluded that China's green policies have improved the governance level of green finance. However, the overall governance level of green finance in China is still low, and there are certain differences in the governance effects of green finance between green policies in the regulatory field and green policies in the fiscal field[5].

In summary, the domestic research methods on green governance are rich, both quantitative and qualitative research. However, quantitative methods pay more attention to the monitoring and evaluation of certain environmental issues and lack a comprehensive evaluation of the efficiency of green governance. Therefore, this paper constructs a green governance efficiency evaluation system, uses super-efficiency DEA model and Malmquist index method to analyze the green governance efficiency of the Yellow River Basin and based on the analysis results, combined with the development plan of the Yellow River Basin, proposes advice for adjusting and optimizing green governance.

3. ESTABLISHMENT OF EVALUATION MODEL AND EVALUATION INDEX

3.1. Evaluation model

3.1.1. DEA model

Charnes, Cooper, and Rhode (1978) have proposed an analytical method for evaluating the relative effectiveness of the same type of decision-making unit (DMU)[6]. This article chooses the DEA model because, on the one hand, the DEA method is more suitable for small samples. This article takes the provinces and cities of the Yellow River Basin as the research object, and the sample size is small, which is suitable for the DEA model. On the other hand, compared with other methods of measuring efficiency such as stochastic frontier analysis, the DEA method has the following advantages: it is much objective, and the weight in the model is determined by the actual data of the input and output of the decision-making unit through mathematical programming. It is concise and convenient, which only needs to know the input and output data, can measure the efficiency through the linear programming method, do not need to know the specific form of the production frontier, and do not need to estimate its parameters and assign variable weight values. DEA can evaluate more accurately. The multi-output situation of the decision-making unit reduces the influence of human subjective factors.

Specifically, for all DMUs, the common BBC model can be used to analyze the production technology of variable returns further to scale and deduce pure technical efficiency and scale efficiency, that is, technical efficiency (TE) = pure technical efficiency (PTE) × scale efficiency (SE), the specific linear

programming is:

$$min\left[\theta - \varepsilon\left(\hat{e}^T S^- + e^T S^+\right)\right]$$

$$s.t.\begin{cases} \sum_{j=1}^{n} X_j\lambda_j + S^- = \theta X_0 \\ \sum_{j=1}^{n} Y_j\,\lambda_j - S^+ = Y_0 \\ \lambda_j \geq 0, j = 1,2,\dots,n \\ S^- \geq 0, S^+ \geq 0, \sum_{j=1}^{n}\lambda_j = 1 \end{cases} \quad (1)$$

In the Formula, λ_j （j=1,2,...,n） is the planning decision variable; $S^-($ $S_1^+, S_2^+,\dots, S_s^+$ $)^T$ is the slack variable vector, and θ （0≤θ≤1） is the planning target value.

3.1.2. Super efficiency DEA model

This paper selects the super-efficiency DEA model proposed by Andersen and Petersen (1993) to evaluate the efficiency of green governance because it overcomes the defect that the BCC model cannot further distinguish the efficiency of multiple effective DMUs enables effective DMUs to be compared and ranked[7]. The super-efficiency DEA model can be obtained by modifying the Formula (1):

$$min[\theta - \varepsilon(\hat{e}^T S^- + e^T S^+)]$$

$$s.t.\begin{cases} \sum_{j=1,j\neq0}^{n} X_j\lambda_j + S^- = \theta X_0 \\ \sum_{j=1,j\neq0}^{n} Y_j\,\lambda_j - S^+ = Y_0 \\ \lambda_j \geq 0, j = 1,2,\dots,k-1,k,K_n \\ S^- \geq 0, S^+ \geq 0, \sum_{j=1}^{n}\lambda_j = 1 \end{cases} \quad (2)$$

The difference between formula (2) and Formula (1) is that the evaluated DMU is removed from the reference set. Its core idea is: the efficiency of the evaluated DMU is derived from the frontiers of other DMUs, and the effective DMU is The super-efficiency value is generally greater than 1, and the larger the super-efficiency value, the higher the efficiency level, and for the DMU that does not reach the DEA effective, the efficiency value will not change.

3.1.3. Malmquist Index

Fare et al. (1989) constructed the Malmquist index $M(x^{t+1}, y^{t+1}, x^t, y^t)$ from period t to period $t+1$ based on the static DEA model[8]. Discuss the dynamic changes of efficiency, where $D^t(x^{t+1}, y^{t+1})D^t(x^t, y^t)$ respectively represent the t period with t period as the technical reference time. The distance function to the evaluation object in $t+1$ period, $D^{t+1}(x^{t+1}, y^{t+1})D^{t+1}(x^t, y^t)$ The meaning is similar.

$$M(x^{t+1}, y^{t+1}, x^t, y^t)=\left[\frac{D^t(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \times \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t+1}(x^t,y^t)}\right]^{1/2} \quad (3)$$

Further decompose investment efficiency (tfpch) into two parts: comprehensive technical efficiency (effch) and technological progress rate (techch), in which comprehensive technical efficiency (effch) can be decomposed into pure technical efficiency (pech) and scale efficiency (sech), then Formula (3) can be decomposed into formula (4):

$$M(x^{t+1}, y^{t+1}, x^t, y^t)= \frac{D^{t+1}(x^{t+1},y^{t+1}|VRS)}{D^t(x^t,y^t|VRS)} \cdot$$
$$\frac{D^{t+1}(x^{t+1},y^{t+1}|CRS)}{D^{t+1}(x^t,y^t|VRS)} \cdot \frac{D^t(x^{t+1},y^{t+1}|VRS)}{D^t(x^t,y^t|VRS)} \left[\frac{D^t(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \times \right.$$
$$\left.\frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t+1}(x^t,y^t)}\right]^{1/2} \quad (4)$$

$$= pech \times sech \times techch=tfpch$$

In this article, if tfpch > 1 means that the governance efficiency is improved, tfpch=1 means that the governance efficiency remains unchanged, and tfpch < 1 indicates that the governance efficiency is reduced.

3.2. Evaluation index establishment

3.2.1. Evaluation System

This paper constructs a green governance efficiency evaluation index system from the two dimensions of input and output to make a comprehensive and systematic evaluation of the status of green governance. The input dimension includes green governance structure and mechanism; the output dimension includes green governance efficiency and green governance environment.

Table 1 Green governance efficiency evaluation index system

Efficient	Dimension type	Dimension	Evaluation Elements of Green Governance Efficiency	Evaluation index	Unit
Green governance efficiency	Investment dimension	Green governance structure	Green organization operation capability	Number of in-service green research and development	People

		Green organization building capacity	Number of green research and development	Piece
	Green governance mechanism	Green service capability	Number of green innovation projects invested by the government	Piece
		Green operation capability	Total government investment in new green innovation fixed assets	100 million yuan
		Green investment capacity	Government spending on green research and development funds	Ten thousand yuan
Output dimension	Green governance effectiveness	Sustainability	1/ Energy consumption per unit of GDP	100 million yuan/10,000 tons of standard coal
		Green transformation capability	Number of environmental technology patent publications	Piece
	Green governance environment	Economic environment	GDP	100 million yuan
		Technical environment	Technology market transaction contract value	Ten thousand yuan

3.2.2. Data Sources

This article takes the provinces and cities of the Yellow River Basin as the research object and selects 2008-2019 as the research period based on data availability and analytical value. The data comes from the "China Statistical Yearbook on Science and Technology", "China High-tech Industry Statistical Yearbook", "China Statistical Yearbook", statistical yearbooks of various provinces and cities, EPS data platform, patent search and analysis system of the National Intellectual Property Administration, etc. This part combines the core connotation of green governance and green innovation to reprocess various raw data, including the number of green research and development in government departments, the number of

green research and development on the job, and the total expenditure on green research and development funds. The number of green innovation projects invested by the government and the total investment in fixed assets for new green innovation is used in practical applications to clarify the connotation of "green". Among the output indicators, the number of environmental technology patent publications was obtained through the "high-tech" and "green" subject terms search of the Patent Search System of the State Intellectual Property Administration.

4. COMPREHENSIVE EVALUATION OF GREEN GOVERNANCE EFFICIENCY OF THE YELLOW RIVER BASIN

4.1. Analysis based on super-efficiency DEA model

Substitute the data of various indicators from 2008

to 2019 into the MaxDEA6.6Pro software, and use the super-efficiency DEA model to evaluate further the green governance efficiency of the provinces and cities in the Yellow River Basin. The super-efficiency evaluation results are shown in Table 2:

Table 2 Green governance efficiency of provinces and cities in the Yellow River Basin from 2008 to 2019

City	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Qinghai	1.202	1.183	1.135	1.144	1.104	1.185	1.191	1.280	1.257	1.288	1.240	1.767
Sichuan	1.033	1.035	1.029	1.036	1.033	1.042	1.045	1.143	1.176	1.134	1.203	1.098
Gansu	1.014	1.036	1.121	1.032	1.034	1.108	1.086	1.065	1.120	1.042	1.018	1.031
Ningxia	1.015	1.045	1.133	1.096	1.143	1.073	1.043	1.035	1.270	1.053	1.041	1.018
Inner Mongolia	1.203	1.147	1.099	1.144	1.148	1.046	1.044	1.042	1.039	1.051	1.073	1.050
Shaanxi	1.103	1.108	1.207	1.134	1.156	1.220	1.185	1.123	1.122	1.122	1.089	1.110
Shanxi	1.107	1.094	1.041	1.087	1.065	1.094	1.111	1.114	1.136	1.146	1.107	1.051
Henan	1.135	1.197	1.251	1.200	1.211	1.198	1.229	1.184	1.154	1.243	1.245	1.227
Shandong	1.175	1.230	1.196	1.262	1.188	1.177	1.174	1.157	1.143	1.191	1.147	1.563
Average	1.110	1.119	1.135	1.126	1.120	1.127	1.123	1.127	1.157	1.141	1.129	1.213
Full range	0.189	0.195	0.222	0.230	0.178	0.178	0.186	0.245	0.240	0.246	0.227	0.209

4.1.1. Time dimension analysis

The efficiency of green governance has experienced a "high-low-high" change trend. Except for a few fluctuations, the green governance efficiency of various provinces and cities in 2010-2014 generally showed a significant downward trend, with a decrease of 1.06%. In 2015 and beyond, the efficiency of green governance in various provinces and cities has shown a fluctuating recovery, increasing 7.42%.

From an endogenous perspective, Prior to the 18th National Congress of the Communist Party of China, all provinces and cities focused on conceptually constructing economical, social and ecological systems for green innovation and green governance, and their substantial investment in green governance was still low. With time, the investment in green governance gradually increases, but the output indicators enter a state of diminishing marginal utility, and the efficiency of green governance decreases. After 2015, provinces and cities formally implemented green governance development strategies and promoted regional green development

through multiple management methods, including subsidies. With the optimization of the green governance input system and the improvement of the quality of green social innovation, the efficiency of green governance has rebounded.

4.1.2. Geographical dimension analysis

The efficiency of green governance in the provinces and cities of the Yellow River Basin in China presents the typical characteristics of small intra-regional gaps and large cross-regional gaps. According to the efficiency value, the green governance efficiency of the Yellow River Basin can be roughly divided into the following three categories:

The first category is mature governance. Henan and Shandong have relatively high overall green governance efficiency. These two provinces are in the lower reaches of the Yellow River Basin, where green innovation is active and green governance is relatively stable. The second category is the advanced governance type. The provinces of Shaanxi, Inner Mongolia and Shanxi in the middle reaches of the Yellow River basin have

intermediate levels of green governance efficiency, but the growth rate has gradually increased in recent years. With the support of the national strategy, its green governance potential is gradually tapped and converted into governance efficiency. These three provinces are becoming the most dynamic areas for green innovation and rapid development of green governance in the Yellow River Basin. The third category is governance development. The four provinces, Sichuan, Gansu, Qinghai, and Ningxia are located in the lower reaches of the Yellow River Basin. Their green governance efficiency is relatively low, but the development momentum is good. Because the Yellow River Basin has

a large green innovation potential and green governance resources need to be developed.

4.2. Dynamic analysis of efficiency based on Malmquist index

Based on the static evaluation of super-efficiency, we further explore the dynamic changes of green governance efficiency. Based on the Malmquist index method, this paper uses MaxDEA6.6Pro software to estimate the dynamic green governance efficiency of the provinces and cities in the Yellow River Basin. The evaluation results are as follows (Table 3 and figure 1):

Table 3 Malmquist index and decomposition of green governance efficiency of provinces and cities in the Yellow River Basin from 2008 to 2019

City	tfpch	techch	effch	pech	sech
Qinghai	1.052	1.062	1.043	1.037	1.025
Sichuan	1.054	1.061	1.047	1.040	1.026
Gansu	1.055	1.056	1.056	1.005	1.047
Ningxia	1.048	1.062	1.039	1.004	1.032
Inner Mongolia	1.053	1.059	1.046	1.003	1.039
Shaanxi	1.055	1.062	1.047	1.003	1.025
Shanxi	1.055	1.062	1.047	1.040	1.025
Henan	1.054	1.060	1.047	1.004	1.039
Shandong	1.056	1.062	1.048	1.041	1.025
Average	1.054	1.061	1.047	1.020	1.031

From an overall point of view, the average dynamic change of the green governance efficiency of the provinces and cities in the Yellow River Basin in China from 2008 to 2019 is 1.054, indicating that the green governance efficiency of the provinces and cities in the Yellow River Basin in 2019 is on the rise, with an increase of 5.36%. According to the decomposition result of the Malmquist index, the 5.36% increase in green governance efficiency is mainly due to changes in the rate of technological progress. The average value of its dynamic change from 2008 to 2019 was 1.061, an increase of 6.07%. At the same time, the comprehensive technical efficiency is greater than 1, indicating that the improvement of comprehensive technical efficiency has promoted the increase in the efficiency of green governance in the provinces and cities of the Yellow River Basin. The pure technical efficiency increased by 1.97%, and the scale efficiency increased by 3.14 %. It is shown to a certain extent that the level of green governance and the return to scale of the provinces and cities in the Yellow River Basin have increased during

the inspection period.

From the perspective of the average change of each year, the green governance efficiency of the provinces and cities in the Yellow River Basin from 2009 to 2019 showed a tortuous and fluctuating trend. (1) From 2009 to 2012, the efficiency of green governance has been on the rise, increasing by 10.4%, 1.3% and 6.4%, mainly due to the increase in the rate of technological progress. (2) From 2013 to 2014, the green governance efficiency of various provinces and cities showed a slight decline, with a decrease of 0.7%. (3) From 2015 to 2016, the efficiency of green governance in the provinces and cities of the Yellow River Basin showed an upward trend, with an increase of 3.7%. (4) From 2017 to 2018, the efficiency of green governance reached a peak period of increase, an increase of 16.8%. The improvement of green governance efficiency benefited from comprehensive technical efficiency, which increased by 22.5%. (5) From 2018 to 2019, the efficiency of green governance in the provinces and

cities of the Yellow River Basin dropped sharply, reaching the lowest value of 0.886, of which the rate of technological progress dropped by 17.8%. It can be concluded that the rate of technological progress has a greater impact on the efficiency of green governance, which fully demonstrates that whether the government can support and carry out effective technological investment and innovation is an important constraint affecting the improvement of green governance efficiency.
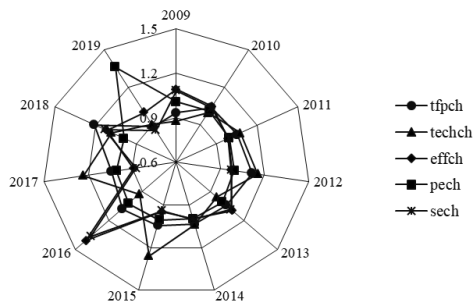

Figure 1 Radar chart of the annual average change of green governance efficiency from 2009 to 2019

5. CONCLUSION

This paper uses the super-efficiency DEA model and the Malmquist index method to comprehensively evaluate the green governance efficiency and change trends of the provinces and cities in the Yellow River Basin. The main conclusions are as follows: First, from the results of the super-efficiency DEA, the green governance efficiency of the provinces and cities in the Yellow River Basin presents typical characteristics of small intra-regional gaps and large cross-regional gaps. Judging from the Malmquist index, the green governance efficiency of the provinces and cities in the Yellow River Basin is on the rise, and the increase in green governance efficiency is mainly due to changes in the rate of technological progress. Moreover, innovation is an important constraint that affects green governance efficiency. From the perspective of the average change in each year, the green governance efficiency of various provinces and cities has shown a tortuous and fluctuating trend.

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