

Research on Regional Green Innovation Efficiency in China: Based on DEA-Malmquist Model

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Received: 25 June 2024; Accepted: 14 July 2024; Published: 27 July 2024

Abstract:

As the core driving force of green development, green innovation has immeasurable value for enhancing regional innovation ability and promoting regional economy to achieve sustainable development goals. This paper takes 30 provinces in China as the research object, takes panel data from 2012 to 2020 as the sample, takes R&D personnel equivalent, R&D expenditure stock and provincial electricity consumption as input indicators, takes green patent applications and new product sales revenue as output indicators, and calculates the green innovation efficiency of each region in China based on DEA-malmquist model. And further carry out the efficiency decomposition and comparison to obtain the status quo and distribution pattern of green innovation capability in different regions. The conclusions are as follows: (1) the overall green innovation efficiency of all regions has improved, but the level is uneven and the gap is obvious; (2) the improvement of green innovation efficiency in all regions was mainly due to the improvement of technological progress; (3) pure technical efficiency and scale efficiency jointly determine comprehensive technical efficiency.

Keywords:

Green Innovation Efficiency, DEA-malmquist, Total Factor Productivity, Comprehensive Technical Efficiency

1. Introduction

In the current era of globalization, the prosperity of the world economy has also brought about the intensification of environmental problems, and the importance of green development has become increasingly prominent. On Oct 6, 2022, data from IQAir, a global air quality tracking platform, showed that 42 of the 100 cities with the most polluted air in the world in 2022 will be in China [1]. Of the 37.4 billion tons of global carbon emissions in 2023, China's carbon emissions reached 12.6 billion tons, and China alone accounts for 35 percent of global carbon dioxide emissions. These figures show that over the past four decades since the reform and opening up, China

has not only witnessed rapid economic development, but also faced increasingly severe environmental challenges.

In order to change the extensive development model of “large production, large consumption and large emission”, the central and local governments are committed to “promoting the green transformation of development mode”. The report to the 20th National Congress of the CPC pointed out that “promoting green and low-carbon economic and social development is a key link to achieve high-quality development” [2]. Building a sustainable future on the basis of green development and seizing the strategic heights of science and technology with innovation as the lead, this two-wheel drive strategy has significantly enhanced China’s international influence and ability to resist risks. However, at present, China still faces the challenge of low overall level in the field of green technology innovation, which is deeply rooted in the imbalance of green development among regions, resulting in a significant regional gap in the efficiency of green technology innovation [3]. Viewed from a regional perspective, green technology innovation is a complex systematic project, and its efficiency is a direct reflection of the close cooperation and interaction of multiple innovation entities [4]. In view of the significant differences between regions in resource endowment, economic foundation and development stage, the innovation resources mastered by innovation entities in different regions and their allocation efficiency among them naturally show diversified characteristics. Therefore, in-depth analysis of regional differences in green technology innovation and the causes behind it from the macro level is of far-reaching significance for precise policies and narrowing the gap in the level of green technology innovation among regions, which is conducive to implementing the concept of green development and achieving high-quality economic development.

2. Literature Review

2.1. Green Innovation

Fussler and Jamnes (1996) first put forward the concept of “green innovation”, which represents a new product and technology paradigm that can simultaneously achieve the dual goals of economic value creation and environmental protection. Subsequently, the concept spread rapidly, arousing extensive interest and in-depth discussion in the academic circles. Green technology innovation is one of the key driving forces behind the positive correlation between environmental protection and economic growth revealed by the environmental Kuznets curve [5]. Green technology innovation, as a key bridge to achieve the dual goals of ecological environmental protection and economic growth, is increasingly becoming the focus of academic attention. However, due to the differences in research perspectives and emphases, the definition of the connotation of green technology innovation has not yet reached a broad consensus. Some scholars tend to view green technology innovation as a comprehensive technological and technological innovation activity from the environmental perspective, whose core goal is to reduce energy consumption and environmental pollution, so as to promote the green transformation of social economy. [6], another part of scholars focus on the level of technological innovation, and regard green technological innovation as a comprehensive system, covering green design, green research and development, green production and green transformation and other closely related sub-processes [7]. No matter from the environmental perspective or emphasizing innovation elements, the existing researches have unanimously integrated innovative activities and environmental protection concepts into the core

concept of green technology innovation. Therefore, this paper defines green innovation as a series of comprehensive and systematic innovation activities implemented by innovation entities to improve resource utilization efficiency and promote ecological environmental protection.

2.2. Efficiency of green innovation

As for the measurement of green innovation, in addition to simply measuring the number of green patents, more scholars tend to measure the efficiency of green innovation from the dimension of technical efficiency. There are three main methods to measure the efficiency of green innovation: Some scholars use a single index to measure the input, output or management of enterprises' green innovation activities, and then evaluate the efficiency of green innovation [8]; In addition, there are also studies using the input-output analysis framework and stochastic frontier method (SFA) to conduct quantitative evaluation of green innovation activities [9]. However, the application of SFA model solves the one-sidedness problem of a single index to a certain extent, but there are still subjective influences in the application process [10]. Some scholars use data envelopment analysis (DEA) to measure green innovation efficiency. Zhang Zaixu uses super-SBM model to measure the green technology innovation efficiency of 30 provinces in China [11]. Qian Li incorporated the non-expected output into the output index system, and calculated the green technology innovation efficiency of enterprises in various provinces in China from 2008 to 2017 through the common frontier SBM-DEA model [12]. With the help of the network SBM-DEA model and the Malmquist index model, Tian Ze comprehensively analyzed the performance of advanced manufacturing industry in the field of green technology innovation in the Yangtze River Delta [13].

To sum up, each method to measure the efficiency of green innovation has its own advantages, the core of which lies in the careful selection of suitable and efficient methods according to the specific research problems, data availability and other factors. In view of the purpose of this study to comprehensively analyze and track the static level and dynamic evolution trajectory of green innovation efficiency in each province, we adopted DEA-Malmquist model as an analysis tool. The model cleverly deconstructs the static data into two dimensions of technological efficiency change index and technological progress index, aiming to gain insight into the vertical evolution of the green innovation efficiency of each city over time during the study period, so as to provide a solid empirical basis for policy formulation and future development strategy.

3. Research Methods and Models

3.1. Research Methods

Data Envelopment Analysis (DEA) is an efficient evaluation method proposed by A. Charnes et al., A famous operational research scientist, in 1978 [14]. This method is specially designed for evaluating decision units (DMU) that contain multiple input and output variables. DEA evaluates relative efficiency objectively by analyzing input-output data of DMU. It does not need to presuppose the production function, directly builds the model based on the actual data, improves the objectivity and accuracy of the evaluation, and provides a reliable basis for decision makers.

Shen Hui pointed out that DEA model reveals the efficiency level of different enterprises at a certain point in time, and its characteristics based on cross-sectional

data make it a static evaluation tool [15]. Among the many criteria to measure the success of innovation, the improvement of total factor productivity is regarded as the core indicator. It is not only the driving force of economic growth, but also the key indicator to evaluate the efficiency of innovation. In order to capture the dynamic changes of TFP in a more comprehensive way, Fare et al. (1994) introduced Malmquist index within the DEA framework, which achieved quantitative analysis of the changes of TFP by comparing the distance function ratio of input-output efficiency in different periods [16]. Malmquist index is dedicated to evaluating the change of total factor productivity (TFP), and its advantage lies in in-depth analysis of the dynamic change of green innovation efficiency. Given the complex multi-input and multi-output nature of green innovation activities, it is difficult for a single indicator to fully capture their efficiency. The Malmquist index fills this assessment gap.

3.2. Research Model

Output-based Malmquist total factor productivity can be expressed as:

$$M_i = (X^{t+1}, Y^{t+1}, X^t, Y^t) \\ = \left\{ \left[\frac{d_a^t(x^{t+1}, y^{t+1})}{d_a^t(x^t, y^t)} \right] \times \left[\frac{d_a^{t+1}(x^{t+1}, y^{t+1})}{d_a^{t+1}(x^t, y^t)} \right] \right\}^{1/2} \quad (1)$$

Where: denotes Malmquist index; $M_i(x^t, y^t)$ Respectively represents the input vector and output vector in period t ; $d_a^t(x^t, y^t)$ And represent the technical efficiency level of t and $t+1$ based on the technical level of t period; $d_a^t(x^{t+1}, y^{t+1})$ And, $d_a^{t+1}(x^{t+1}, y^{t+1})$ respectively, represents the technical efficiency level of t and $t+1$ based on the technical level of $t+1$. The Malmquist index is specifically used to reveal the trend of efficiency change in two adjacent time periods. When the Malmquist index is greater than 1, it is a clear indication that the overall efficiency has achieved a positive improvement over this period. If the index value is equal to 1, it means that the efficiency level has remained stable between the two time periods, with no significant changes. When the Malmquist index is less than 1, it is a warning signal that there has been a decline in overall efficiency, and further investigation and analysis may be needed to identify the specific causes of the decline [17].

Further, Malmquist index method, with its unique analytical framework, deeply divides the change of productivity into two dimensions: technological change and technological efficiency change. This subdivision not only reveals the internal logic of productivity change, but also makes it possible to deeply explore the reasons behind it. Furthermore, technical efficiency change can be broken down into pure technical efficiency change and scale efficiency change. The decomposition formula is as follows:

$$tfpch = effch \times techch = pech \times sech \times techch \quad (2)$$

$$effch = \frac{d_a^{t+1}(x^{t+1}, y^{t+1})}{d_a^t(x^t, y^t)} \quad (3)$$

$$techch = \left\{ \left[\frac{d_a^t(x^{t+1}, y^{t+1})}{d_a^{t+1}(x^{t+1}, y^{t+1})} \right] \times \left[\frac{d_a^t(x^t, y^t)}{d_a^{t+1}(x^t, y^t)} \right] \right\}^{1/2} \quad (4)$$

Where, $pech$ is the pure technical efficiency change, $sech$ is the scale efficiency change, $effch$ is expressed by the product of $pech$ and $sech$. $pech$ is an important index to measure the effect of the efficiency of the evaluated object caused by the change of

technical level. When its value is greater than 1, it indicates that the technical level of the object has improved; On the contrary, if the pech value is less than 1, it indicates that the technical level has declined. sech is an index used to evaluate whether the production and operation scale of the evaluated object is in the optimal state. When the value of sech is greater than 1, it indicates that the scale efficiency has been improved, which is conducive to further improving the production efficiency; on the contrary, if the value of sech is less than 1, it indicates that the current production scale may be unreasonable and the scale efficiency deteriorates [18].

4. Index Selection and Data Source

4.1. Index Selection

The construction of index system is a common method for quantitative research, and scientific index selection can provide a better basis for empirical results [19]. In DEA analysis, the selection of evaluation indicators will significantly affect the effectiveness of the model and the accuracy of the results. To be representative, DEA needs to ensure that the selected evaluation indicators can reflect the main characteristics of the problem studied and the industry, and can comprehensively describe the business nature and performance of the research object.

(1) Input index. According to scholars' research, it is mainly divided into three aspects: human, financial and resource input. In the research of green innovation, the equivalent of R&D personnel and the stock of R&D expenditure are the key inputs of manpower and capital. Equivalent refers to the calculation of R&D personnel according to the actual time of R&D personnel engaged in R&D, and at the same time, the R&D price index should be taken into account, and the R&D expenditure should be flattened. In terms of resource utilization, the power consumption of each province represents the energy input to comprehensively evaluate the resource utilization of green innovation.

(2) Output indicators. Output indicators can be divided into innovation output and economic output. The number of patents is often used to measure innovation output, but the number of patent grants may have a time lag and be interfered with by non-technical factors [20], and most scholars prefer the number of patent applications to represent innovation output [21]. In this paper, the number of green patent applications is selected as the representative of innovation output. In terms of economic output, the sales revenue of new products directly reflects the market value of technological innovation [22], so it is selected as an indicator of economic output.

Finally, the evaluation index system of green innovation efficiency determined in this paper is shown in Table 1:

Table 1. Green innovation efficiency input and output indicators.

Index type	Level 1 Indicator	Secondary indicators
Input indicators	Manpower input	R&D personnel equivalent (person/year)
	Capital input	R&D fund stock (ten thousand yuan)
	Energy input	Provincial electricity consumption (billion KWH)
Output indicators	Green output	Number of green patent applications (pieces)
	Innovation output	New product sales revenue (ten thousand yuan)

4.2. Data Sources

This paper is based on the panel data of 30 provinces in China's mainland region (excluding Tibet) from 2012 to 2020, all raw data are derived from China Statistical Yearbook, China Environmental Statistical Yearbook and provincial statistical Yearbook.

5. Analysis of Regional Green Innovation Efficiency in China

5.1. Overall efficiency analysis

With the help of DEAP2.1 software, the Malmquist index, namely the efficiency of green innovation and its decomposition efficiency, was measured in various regions from 2012 to 2020, as shown in Table 2.

5.1.1. Overall analysis of green innovation efficiency

It can be seen that the efficiency of green innovation in different regions of China is uneven and the gap is obvious. The growth rates of Qinghai, Xinjiang, Inner Mongolia and Beijing were as high as 41.1%, 17.8%, 10.3% and 10.2%, respectively. Heilongjiang, Shaanxi, Shanxi, Jiangxi, Hebei, Guangxi, Hainan and Guangdong also maintained high growth rates, with growth rates ranging from 5.3 percent to 9.9 percent. The green innovation efficiency of Henan, Hubei, Anhui, Liaoning, Jiangsu, Zhejiang, Shanghai, Ningxia, Jilin and Shandong is close to 1, basically showing stable; In the remaining provinces, the green innovation efficiency value is less than 1, and its green innovation efficiency shows a regressive trend, but the decline is not large, staying within 3%. It can be seen that there is a significant gap between Qinghai with the highest growth rate and Fujian with the lowest growth rate. In addition, the overall efficiency of green innovation has increased, indicating that new technical knowledge has promoted the development of green innovation, but the effect is modest. On the whole, except for 8 regions such as Fujian, Hunan and Gansu, the green innovation efficiency value of the other 22 regions is greater than 1, and the mean value of green innovation efficiency of all regions (1.052) is greater than but close to 1, indicating that the green innovation efficiency of most regions in China maintains a certain annual growth rate, but the growth rate is limited.

5.1.2. Decomposition analysis of green innovation efficiency

The green innovation efficiency (TFP) is divided into technology progress (techch) and technology efficiency change (effch). Comparing the two data, it is obvious that the growth of TFP is mainly due to the significant enhancement of technological progress. Among the 22 regions with TFP exceeding 1, except Henan (0.975), Hubei (0.994) and Anhui (0.993), the techch value of the remaining 19 regions broke the threshold of 1. What is particularly striking is that Qinghai, Xinjiang, Inner Mongolia and Beijing, the top four in TFP ranking, have techch values of 1.081, even the lowest one in Inner Mongolia, ranking among the top four in national techch value, highlighting the core role of technological progress in improving regional green innovation efficiency.

At the same time, from a national perspective, all regions in China show a more balanced and positive development trend in green innovation efficiency. Specifically, the average change of comprehensive technological efficiency in the 30 regions remained around 1.020, while the average level of technological progress reached 1.030, both of which were close to the benchmark value 1. This is not only an affirmation of the steady advancement of technological progress, but also a sign that

all regions in China have achieved a more balanced development on the road of green innovation.

Table 2. *Decomposition of average efficiency of green innovation in China from 2012 to 2020.*

firm	effch	techch	pech	sech	tfpch
Pekin	1	1.102	1	1	1.102
Tianjin	0.987	1.006	0.999	0.987	0.993
Hebei	1.017	1.051	1.057	0.962	1.069
Shansi	1.047	1.033	1.038	1.009	1.081
Inner Mongolia	1.021	1.081	1.006	1.015	1.103
Liaoning	0.96	1.072	0.976	0.984	1.029
Ji Lin	1	1.014	1	1	1.014
Amur	1.055	1.042	1.047	1.007	1.099
Shanghai	1	1.018	1	1	1.018
Jiangsu	1.026	1.002	1	1.026	1.027
Zhejiang	1.023	1.001	1	1.023	1.024
Anhui	1.039	0.993	1.038	1.001	1.031
Hokkien	0.983	0.989	0.985	0.997	0.972
Jiangxi	1.061	1.018	1.055	1.006	1.08
Shandong	0.98	1.029	0.967	1.014	1.009
Henan	1.073	0.975	1.067	1.006	1.046
Hubei	1.049	0.994	1.05	0.999	1.043
Hunan	0.986	0.993	0.973	1.014	0.979
Canton	1.049	1.004	1.021	1.027	1.053
Guangxi	1.017	1.049	1.018	0.999	1.066
Hainan	1.02	1.044	1	1.02	1.065
Chungking	1.004	0.992	1.004	1	0.996
Szechuan	0.99	1.003	1.003	0.987	0.992
Guizhou	0.977	1.013	0.954	1.025	0.99
Yunnan	0.97	1.026	0.949	1.022	0.995
Shaanxi	1.012	1.075	1.012	1	1.087
Gansu	0.955	1.027	0.949	1.007	0.981
Qinghai	1.259	1.123	1	1.259	1.414
Ningxia	0.965	1.052	0.934	1.034	1.015
Xinjiang	1.074	1.097	1.032	1.041	1.178

5.2. Dynamic analysis of development

Through the dynamic comparative analysis of the TFP index and its decomposition components in each year (as shown in Table 3), we can clearly observe that the comprehensive technical efficiency shows a fluctuating upward trend from 2012 to 2020. Specifically, during the period from 2012 to 2018, the comprehensive technical efficiency achieved a small and steady increase, and this positive change was mainly due to the significant improvement of scale efficiency. This indicates that during this period, the scale of investment in green innovation activities in various regions has expanded, which in turn has promoted the improvement of green innovation efficiency.

However, it is worth noting that between 2018 and 2019, the combined technology efficiency experienced a significant decline, which was mainly driven by a large decline in pure scale efficiency. This suggests that although the initial scale expansion has played a positive role in improving efficiency, there may also be a certain diminishing marginal effect, or an efficiency loss caused by inadaptability in the process of scale adjustment.

In addition, from Table 3, we can also find that since 2015, the comprehensive technical efficiency has climbed from 0.986 to 1.107, achieving a relatively obvious growth. The root cause of this transformation is that both pure technical efficiency and scale efficiency have achieved significant improvement. The improvement of pure technical efficiency reflects the progress of green innovation technology and management level in each region, while the further improvement of scale efficiency indicates that after a period of adjustment, the scale and efficiency of green innovation activities in each region have reached a more optimized matching state.

Table 3. *TFP and its composition of green innovation in China from 2012 to 2020.*

year	effch	techch	pech	sech	tfpch
2012 ~ 2013	1.177	0.902	1.085	1.085	1.062
2013 ~ 2014	0.937	1.047	0.985	0.951	0.981
2014 ~ 2015	0.99	1.045	0.985	1.005	1.034
2015 ~ 2016	0.966	1.116	0.946	1.021	1.077
2016 ~ 2017	1.014	1.111	1.001	1.013	1.127
2017 ~ 2018	1.137	0.89	1.086	1.047	1.011
2018 ~ 2019	0.798	1.283	0.877	0.91	1.024
2019 ~ 2020	1.195	0.906	1.086	1.101	1.083
Average	1.019	1.03	1.004	1.015	1.049

Between 2012 and 2020, the mean value of technological progress is 1.03, which has no overall effect on the efficiency of green innovation. However, inter-regional analysis shows that technological progress can significantly promote green innovation in high-efficiency regions, while the contribution is limited in low-efficiency regions, showing polarization. This highlights the urgency of upgrading technological progress. Technological progress as a whole shows a small and steady growth trend, except for the large fluctuations from 2016 to 2020.

5.3. Spatial feature analysis

According to the mean of the actual total factor productivity scores of each city from 2012 to 2018, green innovation in 30 regions in China is divided into four categories, as shown in Table 4.

Table 4. *Classification of China's green innovation efficiency by region.*

Classification	Number	Cities
Category 1	4	Qinghai, Xinjiang, Inner Mongolia, Beijing
Second category	8	Heilongjiang, Shaanxi, Shanxi, Jiangxi, Hebei, Guangxi, Hainan, Guangdong
Category 3	10	Henan, Hubei, Anhui, Liaoning, Jiangsu, Zhejiang, Shanghai, Ningxia, Jilin and Shandong
The fourth category	8	Chongqing, Yunnan, Tianjin, Sichuan, Guizhou, Gansu, Hunan, Fujian

Table 4 shows that Qinghai, Xinjiang, Inner Mongolia and Beijing lead in green innovation efficiency, and Qinghai and Xinjiang contribute significantly to technological progress and comprehensive technical efficiency; Beijing and Shanghai mainly rely on technological progress to improve their efficiency, and their contribution to comprehensive technological efficiency is limited. On the other hand, Fujian, Hunan and Gansu were at the bottom in terms of efficiency, reflecting their weak ability to transform productivity in science and technology. Instead of promoting green economy, resources were misallocated due to ineffective transformation of input, which restricted green development.

6. Conclusions

“Green development” and “technological innovation” are the core of economic reform, solve the dilemma of “growth-pollution”, and help the sustainable development of regional economy. This paper focuses on the improvement of provincial innovation ability, adhering to the concept of “green + innovation”, and analyzes the current situation and layout of regional innovation in a spatio-temporal dual dimension. In view of the current situation of green innovation efficiency, this paper puts forward the following suggestions:

First of all, facing the current situation of significant regional differences in green innovation efficiency, regional coordination and differentiated development strategies should be strengthened. Through the establishment of regional cooperation mechanisms and policy guidance, the effective flow of resources and technologies among regions should be promoted, and at the same time, each region should be encouraged to develop green industries according to its own characteristics, so as to narrow the gap in green innovation efficiency among regions.

Secondly, technological progress is the key to improving the efficiency of green innovation. We should increase investment in scientific research, promote industry-university-research cooperation, and accelerate the transformation and application of scientific and technological achievements. At the same time, we should actively introduce advanced green technologies from abroad, and through digestion, absorption and re-innovation, enhance the local green innovation capacity and form a sustained driving force for technological progress.

Finally, in order to comprehensively promote the development of green innovation, it is necessary to improve the green innovation system and promote the development of green industry. Formulate green innovation strategies, improve regulations and standards, establish a green innovation service platform, strengthen personnel training, and provide all-round support for green innovation. At the same time, we will vigorously develop clean energy and green manufacturing, promote green and low-carbon production processes, and achieve sustainable economic and social development.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Funding

This work was supported by Anhui University of Finance and Economics Graduate Research Innovation Fund Project Name: Study on the influence mechanism and path of environmental decentralization on the efficiency of manufacturing green innovation in the context of Yangtze River Delta integration; (Project Number: ACYC2022065).

References

- [1] Xia, J.H.; Liu, S.; Ding, C.F et al. Environmental regulation and green Total factor Productivity: Promote or Inhibit? *Economic Issues*, 2024, 04, 60-67.

- [2] Zhang, X.D.; Ding, X.X. Promote the Great Ship of the Great Rejuvenation of the Chinese nation to brave wind and waves and sail far. *People's Daily*, 2022-10-26(001).
- [3] Zhang, J.Q.; Hou, Y.Z.; Liu, P.L. et al. Objective requirements and strategic path of high-quality development. *Management World*, 2019, 35(07), 1-7.
- [4] Wang, W.; Qin, Y.G. Improvement Path of regional green technology innovation efficiency from the perspective of four spirals: Qualitative comparative analysis based on fuzzy sets of 30 provinces in China. *Science and Technology Management Research*, 2023, 43(01), 206-214.
- [5] Song, M.; Fisher, R.; Kwoh, Y. Technological challenges of green innovation and sustainable resource management with large scale data. *Technological Forecasting And Social Change*, 2019, 144, 361-368.
- [6] Barbieri, N.; Marzucchi A.; Rizzo U. Knowledge sources and impacts on subsequent inventions: Do green technologies differ from non-green ones? *Research Policy*, 2019,49(2), 1-41.
- [7] Cheng, Q.W.; He X.X.; Li, B.S. Green technology innovation efficiency and its influencing factors: an empirical study based on 35 industrial sectors in China. *Journal of Central South University (Social Science Edition)*, 2019, 26(2), 97-107.
- [8] Luo, L.W.; Liang, S.R. Green technology innovation efficiency and factor decomposition of regional industrial enterprises in China. *China Population, Resources and Environment*, 2016, 26(09), 149-157.
- [9] Huang, W.H.; Wang, M.D. Measurement of innovation efficiency of green technology in manufacturing industry of Yangtze River Economic Belt. *Statistics and Decision*, 201, 37(19), 61-63.
- [10]Huang, Y.; Wang, Y.B. How does high-speed railway affect green innovation efficiency? A perspective of innovation factor mobility. *Journal of Cleaner Production*, 2020, 265, 121623.
- [11]Zhang, J.W.; Huang, Z.L. Research on efficiency measurement and influencing factors of interprovincial green technology innovation in China. *Resources and Industries*, 2019, 22(6), 1-8.
- [12]Qian, L.; Wang, W.P.; Xiao, R.Q. Green innovation efficiency and technology gap of Chinese enterprises from the perspective of high-quality development. *Journal of Management Engineering*, 2021, 35(6), 97-114.
- [13]Tian, Z.; Wang, R.M.; Xiao, Q.W.; Ren, F.R. Research on green technology innovation efficiency of Advanced Manufacturing Industry in Yangtze River Delta. *Journal of Anhui Normal University (Humanities and Social Sciences Edition)*, 2021, 49(05), 137-147.
- [14]Charnes, A.; William, W.C.; Edwardo, R. Measuring the efficiency of decision making units. *European journal of operational research*, 1978, 2(6), 429-444.
- [15]Shen, H.; Zhu, L. Evaluation of input-output efficiency of higher Vocational education funds in China: Based on DEA and MLP models. *Research on Education Finance and Accounting*, 2023, 34(06), 76-87.
- [16]Fare, R. et al. Productivity growth, technical progress, and efficiency change in industrialized countries. *American economic review*, 1994, 84(1), 66-83.

- [17] Lei, Y.X.; Zhu, H.Y.; Chen, W.Z. Research on innovation efficiency improvement path of “specialized and innovative” smes from the perspective of dual innovation: An empirical analysis based on DEA-Malmquist and fsQCA. *Journal of Contemporary Economics*, 2019, 41(06), 74-82.
- [18] Zhang, L.K.; Zhang, Y.P.; Liang, Y. Measurement and evaluation of green technology innovation efficiency of Chinese industrial enterprises: An analysis based on super-efficiency network SBM-Malmquist model. *Journal of Technical Economics*, 41(07), 3-22.
- [19] Peng, Z.L.; Zhang, A.P.; Wang, S.F. et al. Design principle and construction process of comprehensive evaluation index system. *Scientific Research Management*, 2017, 38(S1), 209-215.
- [20] Zhang, J.R.; Kang, L.L.; Sun, J.J. Research on the role of newness and temporality in knowledge fusion of science and technology. *Journal of Information Resources Management*, 1-17 [2024-07-12].
- [21] Xiao, R.Q.; Ding, J. Green Innovation efficiency and its spatial spillover effect of Chinese enterprises: Based on two-stage value chain perspective. *Journal of Shanxi University of Finance and Economics*, 2017, 39(12), 45-58.
- [22] Zhang, D.; Wang, H.J. Financial agglomeration, spatial spillover and regional industrial green innovation efficiency. *Economic Jingwei*, 2021, 38(01), 134-142.



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