Accounting and Corporate Management (2024)
Clausius Scientific Press, Canada
DOI: 10.23977/acccm.2024.060525
ISSN 2523-5788 Vol. 6 Num. 5

Research on the Evaluation of Green Investment Efficiency of Listed Enterprises in China

Xu Guannan, Kan Lina

Shaanxi University of Science and Technology, Xian, 710000, China

Keywords: Green investment efficiency, DEA Malmquist index, comprehensive technical efficiency

Abstract: Based on panel data of 331 A-share listed companies in China from 2012 to 2022, the DEA Malmquist index analysis method is used to measure the green investment efficiency of enterprises, and the changing trend is observed from a dynamic perspective to further analyze the heterogeneity of green investment efficiency among industries and regions. The results show that the efficiency of green investment by enterprises has significantly improved from 2012 to 2022. The primary and secondary industries rely on scale efficiency to achieve improvement, while the tertiary industry relies on technological efficiency progress to promote it; The technological efficiency in southern and southwestern regions can promote the improvement of total factor productivity, but the performance in northern and northwestern regions is completely different. Technological efficiency has no positive impact on the improvement of green investment efficiency, and may even have a negative impact. Based on this, policy recommendations are proposed to enhance the efficiency of green investment for enterprises, including expanding the scale of green investment, guiding enterprises to actively participate in green technology innovation, and improving corresponding regulatory systems.

1. Introduction

As the Chinese economy enters a new stage of development, how to promote the green upgrading of enterprise industrial structure has become a practical problem that must be solved in the process of China's green and low-carbon transformation. Green finance supports sustainable development of enterprises, focuses on market demand, actively promotes innovation in financial products and services, guides capital flow to green innovation fields, and accumulates strength for achieving the "dual carbon" goal. In April 2024, the People's Bank of China, together with the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Ecological Environment, the State Administration of Financial Supervision and the China Securities Regulatory Commission, issued the Guiding Opinions on Further Strengthening Financial Support for Green and Low Carbon Development, which proposed to "further strengthen capital market support for green and low carbon development". With the support of national policies, China's green investment market continues to expand, and the green finance system is further improved[1-2]. Green investment, as the core of building a green finance system, can help enterprises achieve multidimensional coordinated development of economy, environment, and society, meet the requirements of sustainable development, and adapt to international development trends to meet global product market demand. How to improve the efficiency of green investment in enterprises? How to improve the efficiency of green investment across different industries and regions? These issues have become crucial[7].

Green investment requires companies to pursue environmental protection and efficiency while controlling the ecological climate within a coordinated range, and to maintain sustainable development requirements while pursuing their own benefits [5]. From the perspective of stakeholders, companies can improve their environmental performance by participating in green investments to help society achieve better environmental outcomes [3]. For the calculation of green investment efficiency, domestic scholars currently use methods such as non radial directional distance function method [4], super efficiency SBM model [10], and data envelopment analysis method [8]. Scholars mostly measure the efficiency of green investment and evaluate green investment behavior by using provincial or enterprise level data. At present, the construction of China's green finance system is gradually improving, and the ways in which enterprises participate in green investment are showing a diversified development trend. However, most of the current research analyzes the efficiency of enterprise green investment through cross-sectional data, making it difficult to observe its changes from a dynamic perspective. This article first calculates the green investment efficiency of listed companies in China from 2012 to 2022 through the DEA Malmquist index, and explores the differences in industrial structure and regional differences in green investment efficiency through enterprise types and regions. Based on this, it proposes improvement paths and suggestions for green investment efficiency, providing ideas and references for the comprehensive green transformation of Chinese enterprises.

2. Evaluation methods and variable selection

2.1. Evaluation method: DEA Malmquist index

The DEA Malmquist index is a measure of a company's production efficiency level in an industry using inputs and outputs, used to evaluate the relative effectiveness between similar decision-making units with multiple input and output indicators. The specific construction of the model is as follows:

Assuming there are n decision units, each of which obtains s outputs with m inputs in period t.

$x_j^t = \left(x_{1j}^t, x_{2j}^t, x_{3j}^t, \dots, x_{mj}^t\right)$Indicate the input indicator value of the jth decision unit in period t.

$y_j^t = \left(y_{1j}^t, y_{2j}^t, \dots, y_{sj}^t\right)$Indicate the output indicator values of the jth decision unit in the t-th period, and they are all positive numbers, t=1, 2, 3,…,T.

In the case of variable returns to scale, let the distance function in period t be, and the distance function in period t+1 be; The distance function in period t is, and the distance function in period t+1 $(x^t, y^t)$is.$D_v^t(x^t, y^t) D_v^{t+1}(x^t, y^t)(x^{t+1}, y^{t+1}) D_v^t(x^{t+1}, y^{t+1}) D_v^{t+1}(x^{t+1}, y^{t+1})$

Under the technical conditions of period t, the change in technical efficiency from period t to period t+1 is:

$$M^t = \frac{D_V^t(x^{t+1}, y^{t+1})}{D_V^t(x^t, y^t)}$$

Under the technical conditions of t+1 period, the change in technical efficiency from t period to t+1 period is:

$$M^{t+1} = \frac{D_V^{t+1}(x^{t+1}, y^{t+1})}{D_V^{t+1}(x^t, y^t)}$$

The change in productivity from period t to period t+1 can be calculated by taking the geometric mean of the two Malmquist productivity indices mentioned above

$$\mathrm{M}(x^t, y^t, x^{t+1}, y^{t+1}) = \sqrt[2]{M^t * M^{t+1}} = [\frac{D_V^t(x^{t+1}, y^{t+1})}{D_V^{t+1}(x^t, y^t)} \times \frac{D_V^{t+1}(x^{t+1}, y^{t+1})}{D_V^{t+1}(x^t, y^t)}]^{\frac{1}{2}}$$

Fare et al. (1994) decomposed the Malmquist index into two parts: one is the change in technical efficiency, represented by effch; The second is the movement of the efficiency frontier, known as the rate of technological change, expressed in techch.

The Malmquist index measures the dynamic change index of total factor productivity from t to t+1, represented by M:

(1) M>1, the Malmquist index shows an upward trend from t to t+1, indicating an improvement in efficiency;

(2) M=1, Malmquist index remains unchanged from t to t+1, and efficiency remains unchanged;

(3) M<1, the Malmquist index decreases from t to t+1, and efficiency also decreases.

2.2. Variable selection

2.2.1. Research samples and data sources

This article aims to study the changes in green investment efficiency of A-share listed companies from 2012 to 2022. Therefore, the decision-making unit is selected as companies listed on the A-share market before 2013. This article takes into account the particularity of financial industry operations and draws on Yao Youfu et al. (2024) to select the research object as follows: (1) excluding financial industry enterprises; (2) Excluding ST and * ST companies, 331 A-share listed companies were ultimately selected for DEA Malmquist index analysis. The data in this article mainly comes from the following sources: annual reports of listed companies, social responsibility reports of listed companies, information on listed company websites, CSMAR database, environmental department websites, etc. The expenses for "construction in progress", "management expenses", environmental protection expenses, and the number of green patent applications for enterprises are manually collected and organized in the financial statements of the enterprise, and some missing values have been removed.

2.2.2. Selection of Input and Output Indicators

2.2.2.1. Selection of investment indicators

This article determines the amount of green investment for enterprises based on the definition of green investment, and draws on the research method of Hu Jun et al. [11] to divide the investment amount involved in green investment into two main categories:

One is the expenditure on environmental protection expenses, which refers to the expenses related to environmental protection in the "construction in progress", including technical upgrades, pollution control, and the purchase and construction of desulfurization equipment related to environmental protection. To control the impact of differences in company size, this article adopts the data processing method proposed by Zhang Qi et al. (2019) to standardize the environmental protection investment of enterprises using their year-end total assets. Meanwhile, in order to enhance the readability of the regression coefficients, the standardized environmental investment is multiplied by 100;

The second is the expenditure on greening expenses, which refers to the greening and sewage fees in the "management expenses" item of the enterprise's profit and loss statement. This article adopts the data processing method of Zhang Qi et al. [12], selects this indicator as the enterprise's greening expense expenditure as part of the enterprise's green investment amount, and divides it by the year-end total assets for standardization processing.

Referring to Su Fang et al. [10], select the corresponding number of employees at the end of each year to measure labor input indicators for each enterprise. At the same time, in order to reduce the differences between data, the collected data is standardized uniformly.

2.2.2.2. Selection of output indicators

Green patent application volume: The green patent application volume of enterprises includes the number of independent applications for green inventions, joint applications for green inventions, independent applications for green utility model patents, and joint applications for green utility model patents by listed companies in the same year. Referring to the research of Li Qingyuan et al. [6] on data processing, the green technology innovation level of a company is measured by adding 1 to the number of green patent applications filed by the company in that year and taking the logarithm.

Net profit and operating income: Referring to Xing Shuting et al. [3], enterprise net profit and operating income are important indicators for measuring business performance, reflecting the output of green investment in enterprises. The data is collected through enterprise annual reports, integrated through crawling, and standardized.

The total carbon emissions of that year: Carbon dioxide emissions can reflect the impact of enterprises on air pollution and effectively reflect the effectiveness of green investment by enterprises. This article draws on Xiao Liming et al. [9] to select the total carbon emissions of a company in the current year to reflect the effectiveness of its green investment. At the same time, to avoid the problem of large differences between data groups, the collected data will be standardized before conducting DEA Malmquist index analysis.

All indicator names and calculation methods are shown in Table 1:

Table 1: Input Output Indicators for Efficiency Calculation of Enterprise Green Investment

	Symbol	Indicator Name	Indicator Calculation and Source
Investment indicators	X1	Labor input (unit)	Number of on-the-job employees corresponding to the end of the year
	X2	Environmental protection expenditure (10000 yuan)	Expenditure related to environmental protection in 'construction in progress'
	X3	Greening expenses (10000 yuan)	Greening and sewage fees included in the 'management expenses'
Output indicators	Y1	Number of green patent applications (units)	Total number of independent and joint green invention patent applications by enterprises
	Y2	Net profit (RMB 10000)	Enterprise Income Statement
	Y3	Operating revenue (RMB 10000)	Enterprise balance sheet
	Y4	Total carbon emissions in that year (tons)	CSMAR database, manually adding missing values

2.2.3. Correlation test between input and output indicators

The input-output indicators selected in the DEA Malmquist model need to be in the same direction, so Spearman correlation tests were conducted on the input-output indicators in this study. The results show that there is a significant positive correlation between input-output indicators, which meets the model's requirement for data homogeneity. The test results are shown in Table 2.

Table 2: Speaeman test results for input-output indicators

	business income	Net profit	Total carbon emissions in that year	Labor input	Environmental protection expenditure	Greening expenses
business income	one					
Net profit	0.276**	1				
Total carbon emissions in that year	0.902**	0.290**	1			
Labor input	0.800**	0.275**	0.800**	1		
Environmental protection expenditure	0.712**	0.337**	0.729**	0.813**	1	
Greening expenses	0.385**	0.301**	0.448**	0.435**	0.419**	1

(*) indicates significance at the 10% significance level, (* *) indicates significance at the 5% significance level, and (* * *) indicates significance at the 1% significance level.

3. Analysis of Green Investment Efficiency of Listed Enterprises

3.1. Dynamic Efficiency Analysis of Malmquist Index Results

Based on the selected 331 sample companies, use Deap2.1 software to calculate and decompose the Malmquist index of panel data on green investment efficiency of listed companies. The Malmquist index in Table 3, also known as total factor productivity (tfpch), can be decomposed into the comprehensive technical efficiency change index (effch) and the technological progress index (techch). The comprehensive technical efficiency change index of enterprise green investment efficiency depends on various aspects such as organizational management level, factor allocation method, and factor quality; The technological progress index can reflect the innovation of green production technology and environmental optimization methods in enterprises. When the total factor productivity (tfpch) is greater than 1, it indicates an improvement in the efficiency of green investment in enterprises. The higher the total factor productivity, the closer the decision-making unit is to the production front, that is, the optimal output level.

Table 3: M Index of Green Investment Efficiency of Listed Enterprises from 2012 to 2022

year	effch	techch	pech	sech	tfpch
2012-2013	1.027	1.006	0.998	1.029	1.033
2013-2014	1.013	0.948	1.001	1.012	0.96
2014-2015	1.008	0.968	0.996	1.012	0.976
2015-2016	0.893	1.134	1.007	0.887	1.013
2016-2017	1.051	0.963	0.998	1.053	1.012
2017-2018	1.075	0.934	1.007	1.067	1.004
2018-2019	1.011	1.034	1.001	1.009	1.045
2019-2020	0.995	0.989	1.001	0.994	0.985
2020-2021	0.999	1.069	0.991	1.008	1.068
2021-2022	1.01	0.988	1	1.01	0.998
Average	1.007	1.002	1.000	1.007	1.009

From the perspective of total factor productivity, the average total factor productivity of listed companies from 2012 to 2022 was 1.009, with a growth rate of 0.9%, indicating that the green investment efficiency of listed companies is continuously improving. From the decomposition of total factor productivity, the average annual growth rate of the comprehensive technical efficiency change index of listed enterprises from 2012 to 2022 is 0.7%, and the average annual growth rate of the technological progress index is 0.2%. The impact of technological progress on total factor productivity fluctuates greatly. In 2017-2018, it was only 0.934, indicating the occurrence of technological decline. However, in 2020-2021, it reached 1.069, indicating that technological progress significantly promotes the improvement of total factor productivity; However, technological efficiency promotes the improvement of total factor productivity in a relatively stable manner, and ultimately manifests as changes in comprehensive efficiency more effectively promoting the improvement of green investment efficiency in enterprises.

From the further decomposition of the comprehensive technical efficiency change index, except for the years 2015-2016 and 2019-2020 when the scale efficiency index was less than 1, all other years were greater than 1, indicating that scale efficiency can generally effectively promote the improvement of total factor productivity. In 2015, the concept of green development was officially proposed at the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China. Subsequently, various provinces, cities, and autonomous regions promoted the transformation of green energy, the development of green industries, and the assistance of green finance to improve the field of green development and broaden the channels for green investment. In September 2016, seven ministries and commissions including the People's Bank of China and the Ministry of Finance jointly issued the Guiding Opinions on Building a Green Financial System to promote the continuous expansion of the national green investment market, the diversified development of investment types, and the promotion of scale efficiency more effectively than pure technical efficiency to promote the improvement of green investment efficiency of enterprises. In 2020, the People's Bank of China issued the China Financial Stability Report (2020), which comprehensively assessed the soundness of China's financial system. The report believes that since 2019, the global political and economic situation has become more complex and severe, with a clear trend of economic anti globalization, and the external uncertainty faced by China's economic and financial system has increased. The severe recession of the world economy, the obstruction of industrial and supply chain cycles, the contraction of international trade and investment, and the turbulence of commodity markets have led to a reduction in the scale and efficiency of enterprises' participation in green investment, making it difficult to maintain the previous growth level to promote the improvement of enterprise green investment efficiency.

3.2. Dynamic efficiency analysis of Malmquist index results based on industry classification

3.2.1. Dynamic efficiency analysis of Malmquist index results for the primary industry - agriculture, forestry, animal husbandry and fishery industry

For listed companies in the agriculture, forestry, animal husbandry, and fishery industries, total factor productivity showed an increasing trend from 2012 to 2022, maintaining an average growth rate of 0.94%. From the decomposition of total factor productivity, the comprehensive technical efficiency of enterprises in the primary industry has a more significant impact on total factor productivity than the technological progress index, that is, due to the improvement of organizational management level and optimization of factor resource allocation, the green investment efficiency of enterprises has been improved. Upon further decomposition, the pure scale efficiency index of all enterprises is greater than 1, indicating that scale expansion promotes the improvement of total factor productivity. Since 2015, China has issued a series of documents including the "Reform Plan for

Establishing a Green Ecological oriented Agricultural Subsidy System," "Opinions on Innovating Institutional Mechanisms to Promote Agricultural Green Development," and "Technical Guidelines for Agricultural Green Development (2018-2030)." These documents support the green transformation of agriculture, promote the flow of funds from agricultural, forestry, animal husbandry, and fishery enterprises to green technology innovation and agricultural product green transformation, effectively improve the comprehensive management level and technological innovation capabilities of enterprises, and achieve the efficiency improvement of green investment in enterprises.

3.2.2. Dynamic efficiency analysis of Malmquist index results for the secondary industry - hydropower and gas industry

The hydropower and gas industry used to rely mainly on resource consumption to provide energy support. From 2012 to 2022, the green investment efficiency of this industry has significantly improved, with an average total factor productivity growth rate of 0.84% for green investment efficiency, and most enterprises maintaining a growth rate of 1%. From the further decomposition of total factor growth rate, it can be seen that comprehensive technological efficiency and technological progress jointly promote the improvement of total factor productivity. During the period of 2012-2022, the hydropower and gas industry strongly supported green technology innovation, which improved the industrial energy conversion rate; At the same time, the country actively promotes the green transformation of energy, providing policy incentives and financial subsidies for industries and energy use involved in the "Energy Production and Consumption Revolution Strategy (2016-2030)", encouraging enterprises to actively participate in technological innovation. The number of green patent applications in the hydropower and gas industries continues to rise, effectively promoting industrial technological innovation and improving the efficiency of green investment.

3.2.3. Dynamic efficiency analysis of Malmquist index results for the tertiary industry - business service industry

The business service industry mainly provides services for enterprise commercial activities and belongs to the tertiary service industry, which relies less on resource consumption. From the perspective of total factor productivity, the overall growth rate from 2012 to 2022 remained at 1.09% and steadily improved; From the perspective of total factor productivity decomposition, the average annual growth rate of the comprehensive technical efficiency index is 0.8%, and the average annual growth rate of the technological progress index is 0.28%, which is much higher than the average level of enterprises, indicating that enterprises improve green investment efficiency by improving resource utilization efficiency. From the perspective of the comprehensive technical efficiency change index, the growth rate of the pure technical progress index is 0.33%, and the growth rate of the scale efficiency index is 0.74%. Due to the continuous improvement of the green finance system, the service industry has more opportunities to provide services for the development of green investment, and the impact of scale efficiency on total factor productivity is also relatively high.

In summary, the efficiency improvement of green investment by listed companies engaged in the service industry is significantly higher than that of other industries. The efficiency growth of green investment in the service industry mainly relies on the improvement of comprehensive technological efficiency, and the driving role of technological progress is also significantly higher than that of other industries. But with the combination of traditional industries and technology, the dependence of the primary and secondary industries on resource consumption continues to decrease, resource utilization efficiency continues to improve, and the overall comprehensive technical efficiency index gradually increases. In the future, enterprises will collaborate with regional development, actively adapt to local government policies on green energy transformation, promote green transformation of enterprises, continuously improve scale efficiency, and promote the improvement of green investment efficiency of enterprises. At present, the national policy orientation is still the main reason for enterprises to participate in green investment and undergo green transformation. Therefore, the comprehensive construction of a market-oriented green finance system is still a long way to go.

3.3. Dynamic efficiency analysis of Malmquist index results based on regional division

Based on the location of A-share listed companies determined by the stock exchange, and combined with the calculated distribution concentration of 331 companies, samples from four regions including Southwest, Northwest, South China, and North China were selected for analysis.

3.3.1. Dynamic Efficiency Analysis of Malmquist Index Results in South China

The 45 listed companies in South China cover 19 industry categories classified by the China Securities Regulatory Commission, which can comprehensively demonstrate the changes in green investment efficiency of listed companies in South China. From the perspective of total factor productivity, only 5 enterprises have a total factor productivity less than 1, while the total factor productivity of the remaining enterprises has significantly improved, maintaining an average growth rate of 0.8%, which is basically equivalent to the national average growth rate. From the perspective of total factor productivity decomposition, the comprehensive technical efficiency maintains a growth rate of 0.72%, and the technological progress efficiency maintains a growth rate of 0.16%. The contribution of comprehensive technical efficiency to total factor productivity is more prominent. Further decomposition of the comprehensive technical efficiency index shows that comprehensive management technology, resource allocation efficiency, technological improvement, and production scale expansion all effectively promote the improvement of total factor productivity. In the past few years, the South China region has actively promoted the construction of green financial services, promoted financial service entities, issued green development tax preferential policies and government subsidy methods, improved the green and low-carbon production system, promoted the green transformation of agriculture, industry, and service industries, driven the green development of local enterprises, and achieved an overall improvement in green investment efficiency.

3.3.2. Dynamic Efficiency Analysis of Malmquist Index Results in North China

The total factor productivity of listed companies in North China maintained a growth rate of 0.83%, which is at the national average level. However, there are significant differences in the growth rate of total factor productivity among different industries. The growth rate of total factor productivity in the real estate industry is only 0.2%, but the growth rate of total factor productivity in the information technology industry is 1.35%, and the growth rate of total factor productivity in the accommodation and catering industry is 0.93%, indicating a significant gap between industries. From the decomposition of total factor productivity, technological progress has a relatively small impact and may even have negative effects, thereby inhibiting the improvement of green investment efficiency. Further decomposition of comprehensive technical efficiency reveals that pure technical efficiency has almost no impact or negative effects on comprehensive technical efficiency. This may be due to the fact that most of the enterprises selected in North China are resource consuming enterprises in real estate and coal mines, which have high resource dependence and difficulty in green transformation. They have relatively few green patent applications and acquisitions, which has not effectively improved resource utilization efficiency. Pure technological progress is difficult to promote the improvement of green investment efficiency for enterprises.

There may be three reasons for the differences in green investment efficiency between South China and North China. Firstly, due to differences in topography, resources in South China are relatively scarce compared to North China, and technological progress is needed to promote the improvement of resource utilization efficiency and reduce production costs. The degree of independent participation in green investment by enterprises in southern China is relatively high, and the pure technical efficiency index changes relatively greatly. Second, most enterprises in South China are new Internet industries, information service industries, etc., and most of their production methods are technology intensive enterprises, resulting in a greater contribution to pure technical efficiency. Thirdly, due to different regional development strategies, the industrial clusters formed have different focuses. As a national economic development priority, the South China region has innovative regional policies that can effectively enhance the enthusiasm of enterprises to actively participate in green investment.

3.3.3. Dynamic Efficiency Analysis of Malmquist Index Results in Northwest China

In the northwest region, total factor productivity maintains a growth rate of 1%, slightly higher than the national average growth rate. According to the decomposition of total factor productivity, maintaining a growth rate of 0.78% for comprehensive technical efficiency and 0.21% for pure technological progress both have a positive impact on the growth of total factor productivity. Further decomposition of the comprehensive technical efficiency index reveals that changes in pure technical efficiency have a negative impact on the overall technical efficiency, inhibiting its growth. In recent years, the rapid economic development of various provinces and cities in Northwest China cannot be separated from heavy industry refining industries such as coal chemical and petrochemical, as well as metal raw material industries such as electrolytic aluminum and polycrystalline silicon, which have caused huge harm to the ecological environment. In recent years, China has issued the "Several Opinions on Strictly Restricting Energy Efficiency and Promoting Energy Conservation and Carbon Reduction in Key Areas" (Development and Reform Commission Industry [2021] No. 1464), targeting high energy consuming industries in the northwest region, issuing and dynamically improving the enterprise directory list, fully utilizing new technologies such as big data and cloud computing to carry out energy-saving diagnosis, understanding the comprehensive energy consumption of major energy consuming processes, key energy consuming equipment, and unit products, and carrying out targeted guidance for improving energy efficiency levels based on a chain and policy. Furthermore, in accordance with the transformation requirements proposed in the "Implementation Guidelines for Energy Conservation and Carbon Reduction Upgrades in Key Areas of High Energy Consuming Industries (2022 Edition)" and the "Guiding Catalogue for Industrial Structure Adjustment", we will accelerate the energy-saving transformation and energy cascade utilization of key energy consuming equipment systems. In the next few years, the efficiency of green investment in the northwest region will significantly improve, and technological progress and comprehensive management capabilities will be the key to efficiency improvement.

3.3.4. Dynamic Efficiency Analysis of Malmquist Index Results in Southwest China

The Malmquist index performance of listed companies in the Southwest region is different from that in the Northwest region, with a total factor productivity growth rate of 1%, higher than the national average growth rate of 0.9%. From the decomposition of total factor productivity, the growth rate of the comprehensive technical efficiency change index is 0.68%, and the growth rate of the technological progress index is 0.31%, which has a promoting effect on total factor productivity. Further decomposition of the comprehensive technical efficiency change index shows that pure technological progress increases at a rate of 0.05%, while scale efficiency changes increase at a rate of 0.6%, which can effectively promote changes in the comprehensive technical efficiency index and increase the efficiency of green investment for enterprises.

There is also a significant difference in the efficiency of green investment among listed companies in the southwest and northwest regions. The overall technological progress efficiency in the southwest region has improved significantly, but the growth rate of comprehensive technological efficiency in the northwest region is faster than that in the southwest region. This is mainly due to the faster improvement rate of green investment scale efficiency in the northwest region, and the continuously expanding market size has filled the gap in technological innovation. The long-term economic development of the five provinces and regions in Northwest China lags behind due to factors such as natural conditions, geographical environment, industrial structure, transaction costs, and business environment. Against the backdrop of low-carbon transformation, the economic development of the northwest region is facing enormous challenges. The construction of a carbon trading market and the development of new energy provide possibilities for sustainable development in the future of the northwest region. The overall scale of green investment will continue to expand, and the efficiency of green investment will steadily improve.

4. Conclusion and Suggestions

This article uses the DEA Malmquist index to dynamically analyze the green investment efficiency of 331 listed companies from 2012 to 2022. The results show that: (1) there has been a significant improvement in the green investment efficiency of enterprises, but mainly due to the improvement of the green investment market from 2012 to 2022, which has promoted the increase in the scale of green investment by enterprises, with technological progress playing a relatively small positive role.(2) According to industry types, the improvement of green investment efficiency in agriculture, forestry, animal husbandry, and fishery, as well as manufacturing enterprises, mainly relies on the expansion of investment scale, and the contribution of pure technological progress is relatively small. The comprehensive management capability, subsequent investment efficiency supervision, resource allocation improvement, and pure technological progress of service industries jointly promote the improvement of green investment efficiency of enterprises. (3) The efficiency of green investment in enterprises shows regional differences, and technological progress in South China and Southwest China can promote the improvement of green investment efficiency in enterprises; The technological progress in North China and Northwest China has minimal impact on the efficiency of green investment for enterprises, and may even inhibit the improvement of green investment efficiency.

Therefore, in order to comprehensively improve the efficiency of green investment in enterprises, suggestions are proposed from the following aspects:

Firstly, we need to expand the scale of green investment. At present, the country is actively building a green finance system, and the government guides enterprises to actively participate in economic investment through issuing green bonds, expanding the scale of green credit, establishing a carbon market trading system, and increasing green development funds. Enterprises should actively expand their channels for participating in green investment, actively engage in the green finance market, and improve the efficiency of green investment by expanding economies of scale.

Secondly, guide enterprises to actively participate in green technology innovation. The current lack of motivation and autonomy for enterprises to participate in green patent innovation requires promoting green technology innovation in order to solve the problem of low resource allocation efficiency and further reduce the cost pressure caused by environmental regulations through technological innovation. At the same time, increasing government subsidies and tax incentives can alleviate the cost pressure of enterprises applying for green loans, achieve economic benefits while realizing technological innovation, and maintain the requirements of sustainable development of enterprises.

Thirdly, improve the corresponding regulatory system and enhance the efficiency of fund utilization. Establish a complete investment supervision system to help enterprises achieve dynamic supervision of the entire green investment process, ensuring the rational and compliant use of funds through precise control of funds before, during, and after the event. At the same time, it is necessary to strengthen the post investment supervision system, manage and operate the follow-up engineering facilities of green investment projects, and conduct precise testing for project development. Implementing long-term supervision can effectively promote technological innovation in the field of green investment, scientifically divide the proportion of capital investment and structural allocation, and provide reference for determining new projects in the future.

Acknowledgement

Xianyang Soft Science Project: Research on the Impact Mechanism and Driving Strategies of Technological Innovation in Xianyang Enterprises under the New Development Pattern (L2023-RKXSJ-037)

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