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Study on the Impact of Carbon Financial Transactions on Green Innovation Efficiency

-- From China's Carbon Emission Rights Pilot

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Abstract

Carbon financial trading is an innovative means of utilizing market mechanisms to promote greenhouse gas emission reduction, which is of great significance for achieving low-carbon, green and sustainable development. And green innovation efficiency is a comprehensive index, which reflects the efficiency of resource and technology allocation in the process of green innovation, as well as the potential and ability to achieve high output. Every leap forward in green innovation is toward cleaner, more efficient, and more environmentally friendly goals, and improving the efficiency of innovation is key to ensuring that the process is sustainable and more conducive to sustainable development and environmental protection. This paper takes 15 provinces and cities in our country as the research object. Based on the perspective of input and output, the Super-efficient SBM model is used to measure the efficiency of green innovation in 15 provinces and cities using Matlab, and the Tobit model is used for empirical analysis. The results show that economic agents utilize resources efficiently in the process of production and innovation, and can balance the relationship between economic development and environmental protection well. CDM projects have a significant negative impact on green innovation efficiency, and the impact of CDM projects on green innovation efficiency may be restricted by a variety of factors.

Keywords

Carbon Finance; Green Innovation Efficiency; CDM Clean Development Mechanism.

1. Introduction

While China's economy is developing at a rapid pace, ecological and environmental problems are becoming increasingly severe, and a consensus has been reached on improving the quality of the ecological environment. As global warming becomes more and more severe, the earth is facing unprecedented environmental challenges, the Chinese government has responded positively to the appeals of the international community, and in 2020, the Central Committee of the Party of China put forward a "dual-carbon" goal in the light of the actual situation, with the expectation that under the unremitting efforts of the people of the whole country, the total carbon dioxide emission will reach its peak by 2030. At the same time, we have also set an ambitious goal of achieving carbon neutrality by 2060. Through these two phases of efforts, we will gradually reduce greenhouse gas emissions and promote the transformation and upgrading of the energy structure. Carbon peak, that is, carbon emissions peak and then gradually decline, carbon neutral refers to the future reduction of carbon emissions to zero, that is, through the reduction of carbon dioxide emissions and the implementation of a variety of carbon offset measures, so that carbon dioxide emissions per unit of time equal to the amount of carbon dioxide absorbed per unit of time by various means, so as to achieve the reduction of

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carbon dioxide emissions to the state of zero. The realization of this ambitious goal is not only of great significance to the improvement of China's and even the global ecological environment, but also of great contribution and significance to the sustainable development of human society. We cannot ignore the far-reaching impact of carbon peaks and carbon neutrality, which are wide-ranging and profound changes in economic and social systems. To achieve the goal of carbon neutrality, it is necessary for energy, industry, forestry, construction and transportation industries to work together to reduce carbon emissions by means of technological innovation, optimize China's energy and industrial structure, effectively utilize existing resources and reduce production costs. The core of the "dual-carbon" strategy lies in innovative low-carbon technologies. However, such a large-scale economic and social systemic change is impossible to achieve without huge amounts of capital support. The long investment cycle and low rate of return on the financing required for carbon neutrality require that energy consumption be reduced through green technological innovation and that low-cost energy saving and emission reduction be realized in order to guarantee the realization of the "dual-carbon" goal.

2. Literature Review

Against the background of the current global climate change, China, as the world's largest developing country, has assumed a great responsibility in combating climate change and promoting low-carbon development. Therefore, the study of China's carbon emissions trading market is particularly important. However, due to the influence of various factors such as research perspectives, data sources and policy environment, the research results of scholars on this issue show diverse views.

Research on China's carbon emissions trading market is divided. Corsatea (2014) argued that the driving force of the carbon market must be fully utilized in order to push the innovation of low-carbon technologies to a new level. Guoand Xiao (2020) found through empirical analysis of relevant firms that carbon emissions trading can induce firms' technological innovation. Hoffmann (2007) argued that the price of carbon formed in the process of carbon emissions trading will significantly hinder polluting production technologies and promote clean and low-carbon technologies instead. This implies that if the price of carbon trading is unreasonable, it may inhibit firms' incentives to innovate and lead to the misallocation of resources to polluting production modes. Guo et al. (2021) suggested that China has established several carbon emissions trading pilots, and the establishment of these pilots has promoted the level of regional low-carbon technological innovation. Zhao et al. (2023) indicated that carbon trading can promote enterprises to improve the level of green innovation through the market mechanism. However, there are also scholars who hold different views on this. Shi et al. (2017) showed through empirical analysis of sample enterprises that both regulated and non-regulated companies are significantly inhibited under the carbon emissions trading system. Zhang et al. (2019) concluded that at the current stage, the level of introducing low-carbon technologies is higher than the level of independent research and development, and companies tend to adopt a more conservative low-carbon technology innovation strategy. Wang et al. (2020) found that there are certain differences in the policy effects of China's carbon emissions trading pilots, and there is a "signal-expectation" mechanism that carbon emissions trading promotes low-carbon technological innovation. Zhang et al. (2019) found that from the perspective of various policy effects, the carbon emissions trading pilot can not effectively encourage enterprises to carry out low-carbon technological innovation, but the medium and long-term plan can provide enterprises with long-term and stable policy guidance, which will have a positive and positive effect on the low-carbon investment behavior of enterprises.

Regarding the impact of environmental regulation on technological innovation of enterprises, domestic and foreign scholars have explored more, and the conclusions are different.

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Chakraborty, Chatterjee et al. (2017) found that appropriate environmental regulation can prompt enterprises to introduce green production technology and improve their independent innovation ability. Guo et al. (2020) showed that environmental regulation has an obvious promotion effect on provincial economic development. Porter (1995) argued that the more reasonable the environmental regulation, the greater the promotion effect on the technological innovation of the enterprise, thus making it more likely that the enterprise can achieve a win-win situation for both the environment and the economy. By implementing stricter environmental regulations, Qi et al. (2022) proposed reduce the efficiency loss caused by trade openness, which in turn promotes the efficiency of urban green development. However, Grubb et al.(2005) suggested that market emission rights quota restrictions can cause significant damage to firms' overall innovation activities. Shi and Xu (2018) found that the implementation of environmental regulation policies can lead to a decrease in firms' incentives to innovate on their own, which in turn affects firms' innovation capabilities. Li and Yang (2020) argued that the strengthening of regional environmental regulation makes the production cost of manufacturing enterprises continue to rise, causing more credit resources to tilt towards the manufacturing industry, resulting in a mismatch of financial resources and affecting the efficiency of green development. Zhang et al.(2019) also suggested that administrative order-type energy-saving policies play an inhibitory role for enterprises to carry out low-carbon technological innovation. Wang et al.(2020) found that, on a national scale, controlling environmental regulation has a certain deterrent effect on low-carbon technological innovation. Rogge (2011), Donget al. (2019) showed that there is an inverted U-shape curve relationship between environmental regulation and independent innovation.

Research on the level of green development efficiency, Yang et al.(2017) found that overall, China's interprovincial green development efficiency level is not high, showing a change rule from smooth to rapid to smooth stages; Che et al. (2018) found that China's green innovation level shows significant imbalance among different regions. Wang et al.(2020) found that the green development efficiency is relatively high in the eastern region, and relatively low and similar in the central and western regions. The key to the differences in innovation development between regions lies in the level of economic development, and innovation input factors play a decisive role in the impact of green innovation. In addition, the government's behavior contributes more significantly to the influence of the central region.

CDM refers to emission reduction projects applied by developing countries, where developed countries provide financial or technical support to developing countries, and the saved emission credits can be used to make a request to the United Nations Executive Council to offset the carbon emissions of the developed countries, so that the developed countries can meet the emission reduction targets stipulated in the Kyoto Protocol. Yu et al.(2022) showed that CDM project trading exhibits a significant negative impact on green innovation efficiency. This suggests that under certain circumstances, carbon trading may have a negative impact on green innovation activities. This paper will continue to explore in depth the impact of CDM carbon trading on the efficiency of regional green innovation activities, with a view to providing new perspectives and references for research in related fields.

3. Mechanisms for the Impact of Carbon Finance on Trading on Green Innovation

3.1. The Development of Carbon Finance Promotes the Improvement of Green Innovation Efficiency

Hoffmann (2007) argued that the high carbon price formed in the process of carbon emissions trading makes polluting production technologies gradually withdraw from the trading market instead of promoting clean and low-carbon technologies, which improves the efficiency of

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green innovation. Chakraborty P. et al. (2017) suggest that: the development of carbon finance promotes the the innovation of green financial products and services. In order to reduce the cost of enterprises, financial institutions have continuously explored and innovated in the field of carbon finance, and launched a series of financial products and services for green innovation, such as green bonds and green funds. These financial products and services not only reduce the financing cost of green innovation, but also improve the efficiency of the use of funds, thus promoting the efficiency of green innovation. According to Menghao Zhang (2024), green finance significantly promotes enterprises to carry out green technological innovation. Green finance encourages enterprises to carry out green technology innovation projects by alleviating their financing constraints and improving their risk-bearing ability, and the development of carbon finance promotes the promotion and application of green technologies. Through carbon finance transactions, the value of green technology is better reflected and recognized, thus promoting the wide application of green technology. The use of green technology can not only improve production efficiency, reduce environmental pollution and resource consumption, but also effectively promote the enhancement of green innovation efficiency.

3.2. Government Support Has a Multifaceted Impact on Green Innovation Efficiency

Xu et al. (2022) argue that government support is an important support for high-tech industries to carry out green innovation activities. In order to give full play to the role of government support in promoting the green innovation efficiency of high-tech industries, the government must formulate a reasonable subsidy range according to the actual development of high-tech industries, and follow the principle of adapting to local conditions to formulate feasible government support policies for different regions, industries, and ecological environments. The government provides financial support for enterprises' green innovation by setting up special funds and financial allocations. This move will help alleviate the financial troubles of enterprises in the process of green technology research and development and application, reduce the cost of innovation, and thus promote the in-depth development of green innovation activities and enhance the efficiency of green innovation. Li(2021) suggested that the green technology innovation efficiency of high-tech industries in various provinces is rising year by year with fluctuations, but there are significant differences between provinces. Enhanced government financial support has a significant enhancing effect on the efficiency of green technology innovation in most high-tech industries, especially in the western region, where the effect of such support on efficiency improvement is more significant, and the effect of financial support to promote efficiency is stronger in the Western region. The moderating effects of government support and environmental regulation on green technology innovation efficiency differ in the East, middle and West. According to Li (2020), government scientific and technological support strengthens the role of environmental regulation in promoting green technological innovation efficiency in the East and the center, while this role is not obvious in the West; government support for energy conservation and environmental protection strengthens the role of environmental regulation in promoting green technological innovation in the east, but in the center, it significantly weakened this role; in the west, there is no obvious effect.

Through the implementation of strict environmental regulations, the Government has restricted the development of high-pollution and high-energy-consumption industries and promoted enterprises to accelerate their green transformation. Although environmental regulation may increase the costs of enterprises, in the long run, it helps to promote green innovation, improve resource utilization efficiency and reduce environmental pollution, thereby enhancing green innovation efficiency. However, China's inter-provincial green innovation efficiency level is not high and the level of development is not balanced, so the

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government needs to further improve the relevant policies. Overall, the impact of government support on green innovation efficiency is comprehensive, and these initiatives help to stimulate the innovation motivation of enterprises and promote the in-depth implementation of green innovation activities, which in turn enhances green innovation efficiency.

3.3. The Impact of Foreign Direct Investment on the Efficiency of Green Innovation

Carbon finance, as a low-carbon financial mechanism, aims to channel capital flows into low-carbon technologies and financial activities. These activities not only provide financial support for low-carbon technologies, but also incentivize enterprises to reduce carbon emissions and promote green innovation through the market mechanism. Then foreign direct investment plays an important role in this, and investors with investment vision will put their assets into green projects with innovative prospects and market prospects. First of all, foreign investment will bring advanced technology and experience, which can make up for the shortcomings of domestic green innovation development, promote enterprises to carry out technological upgrading and transformation, and improve the efficiency of green innovation. Secondly, FDI will bring capital supply, promote existing capital investment in various fields and accelerate its flow between fields (Yu Shaolong et al., 2024). In general, when FDI has a positive technology spillover effect, it will promote the level of green innovation efficiency.

3.4. The Impact of Environmental Regulation on the Efficiency of Green Innovation

Environmental regulation, as an important means for the government to protect the environment, can reduce the cost of environmental protection and pollution control of enterprises through green technological innovation so as to realize the innovation compensation, which has a promoting effect on green innovation (Porter, 1995). Environmental regulation can provide the soil and power for the development of carbon finance. With the increasing strength of environmental regulation, the environmental protection costs faced by enterprises are also increasing, at this time, they will seek new financing channels to cope with, carbon finance came into being, providing enterprises with a market mechanism to reduce carbon emissions, realize the path of green transformation. The carbon financial market can help resource-based enterprises to reduce the cost of penalties, and when the enterprise green transformation faces financial constraints, it can also be traded through the carbon financial market, thus increasing the source of profits of enterprises (Wang Kang, 2023). In addition, carbon finance can promote the role of environmental regulation in green innovation. Carbon emissions trading of carbon finance can transform carbon emissions into useful assets through the market mechanism, thus playing a role in reducing carbon emissions and improving energy efficiency. Not only can it reduce the environmental costs of enterprises, but also increase revenue, thus enhancing the incentive for green innovation.

3.5. The Impact of Economic Development on the Efficiency of Green Innovation

Rapid economic development can provide broad market space and demand for carbon finance. Against the backdrop of rapid economic development and accelerated industrialization, problems such as environmental pollution, waste of resources, increased energy consumption and rising carbon emissions are gradually coming to the fore, which undoubtedly pose a serious challenge to the efficiency of green innovation. (Zuo Teng, 2024). Therefore, carbon finance as the optimal solution to reduce carbon emissions and realize green development has gained great market demand. Secondly, economic development can bring the capital base for carbon finance. In the process of economic development, capital accumulation and technological progress are the key factors to promote green innovation. Carbon finance can promote the

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research and development of green technologies and projects by guiding the flow of capital. At the same time, economic development will also bring about industrial upgrading and transformation, so carbon finance can play a role in new energy, green and other fields, which further promotes the deep integration of carbon finance and green innovation.

4. Green Innovation Measurement and Status

4.1. Green Innovation Measurement

Green innovation indicators should take into account the economic and environmental benefits, this paper adopts the super-efficient SBM measurement method, which is better than DEA, DEA is only concerned with the effectiveness of the results of the measurement, and did not incorporate the environmental pollution of such non-desired outputs. SBM model is:

$$\min \rho = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1+\frac{1}{q_1+q_2}(\sum_{r=1}^{q^1}\frac{s_r^+}{y_{rk}}+\sum_{t=1}^{q^2}\frac{s_t^{b-}}{b_{tk}})} \tag{1}$$

$$s.t.\begin{cases} x_{ik} \geq \sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^-(i=1,...,m) \\ y_{rk} \leq \sum_{j=1,j\neq j0}^{n} y_{rj}\lambda_j - s_r^+(r=1,...,q_1) \\ b_{tk} \leq \sum_{j=1,j\neq k}^{n} b_{tj}\lambda_j - s_t^{b-}(t=1,...,q_2) \\ s_i^- \geq 0, s_r^+ \geq 0, s_t^{b-} \geq 0, \lambda \geq 0 \end{cases} \tag{2}$$

In the formula, is the value of green innovation efficiency of DMU to be measured, where represents inputs, desired outputs and non-desired outputs, respectively. The decision-making unit of this paper is 15 developed provincial data, and the input indicators include capital, labor and energy. Capital inputs are represented by internal expenditures of R&D funds; labor inputs are represented by full-time equivalents of R&D personnel; and energy is represented by total electricity consumption. The output indicators cover both desired and undesired output categories. In terms of desired output, we mainly measure it through the number of invention patent applications and new product sales revenue. Among them, the number of invention patent applications effectively demonstrates the substantive results of innovation, which represents the efforts and achievements of enterprises in technology R&D and innovation; while the revenue from new product sales directly reflects the performance of innovation results in the market, which is an important indicator of the market value of innovation. In contrast, non-desired outputs focus on indicators that negatively impact the environment and sustainable development. Specifically, we use three key indicators, industrial wastewater emissions, industrial sulfur dioxide emissions, and solid waste emissions, to measure non-desired outputs. The data are all from the China Statistical Yearbook. The indicator system is shown in table 1 below.

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Table 1. Green Innovation Input and Output Evaluation Indicator System

Primary Index	Secondary Index	Indicator Variable	Unit
Innovation input	Capital input	Internal expenditure of R&D funds	Ten thousand yuan
	Labor input	R&D personnel full-time equivalent	Per person
	Energy input	Total electricity consumption	Hundreds of millions of kilowatt-hours
Innovation output	Expected output	Number of invention patent applications	Set
		Revenue from new product sales	Ten thousand yuan
	Undesirable output	Discharge of wastewater	Ten thousand tons
		Sulfur dioxide emission	Ten thousand tons
		Solid waste discharge	Ten thousand tons

4.2. Status of Green Innovation Efficiency in the Provinces

In this paper, Matlab is used to measure the results of green innovation efficiency value of each province, with 2012 as the base period and the measurement period of 2012-2021. Figure 1 below shows the average change of green innovation efficiency in each province. It can be seen that except for 2012, the average value of green innovation efficiency in other years is above 0.5, and shows an increasing trend year by year. Firstly, these developed provinces have strong economic strength and perfect industrial system, which provide strong talent and technology support for green innovation. Secondly, these developed provinces have higher awareness of environmental protection and policy support when facing environmental problems, and are able to act faster to encourage enterprises to increase green innovation investment. Figure 2 shows the green innovation efficiency values of 15 provinces. It can be seen that the green innovation efficiency values of most provinces are increasing year by year.

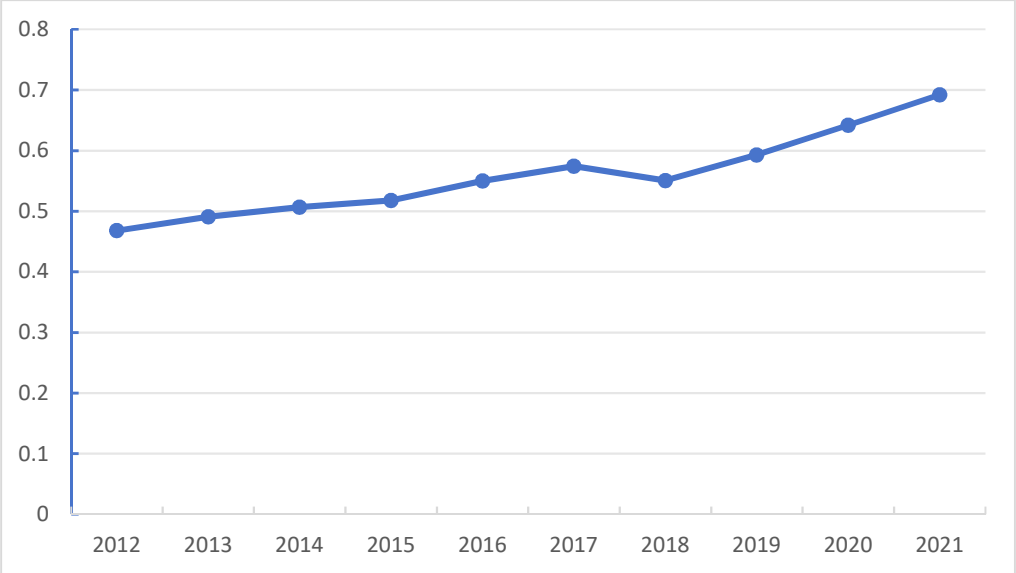

Figure 1. Average Change in Green Innovation Efficiency from 2012 to 2021

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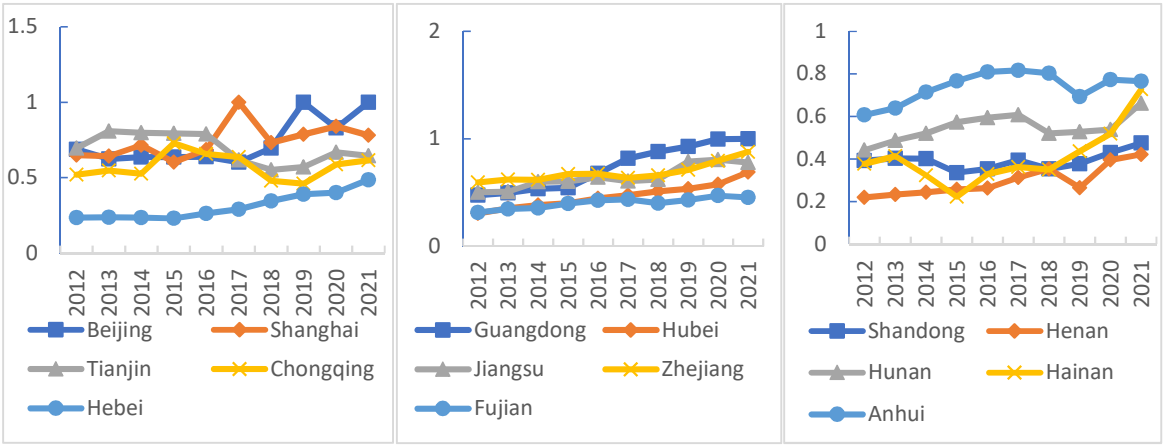

Figure 2. Status of Green Innovation Efficiency Data Levels in 15 Provinces from 2012 to 2021

5. Tobit Analysis of Carbon Finance and Green Innovation Efficiency

China has a positive attitude towards the CDM, emphasizing that CDM projects must at the same time meet the requirements of helping developing countries achieve sustainable development and reduce greenhouse gas emissions. China has also promulgated relevant administrative measures, specifying the priority areas, licensing conditions, management and implementation organizations of CDM implementation, etc., in order to promote the effective implementation of CDM in China. As of 2019, 3,764 CDM projects have been issued within China. This paper further explores the impact of CDM carbon trading on the efficiency of regional green innovation activities.

5.1. Selection and Description of Indicators

Table 2. Selection and Description of Indicators

Serial Number	Name	Code Name	Instructions
1	Green innovation efficiency	ρ	It reflects the input-output efficiency of innovation based on environmental coordination in various regions
2	Carbon finance development	CG	Based on the original data of the estimated carbon emission reduction (CER) of CDM projects approved by each region, CG=CER/GDP is defined, which reflects the estimated carbon emission reduction of CDM projects based on units of GDP; the larger the CG value, the greater the corresponding carbon emission reduction per unit of GDP, indicating the scale of carbon finance based on CDM projects. The larger the variable, the smaller the variable; the relevant data for this variable comes from the official website of the China Clean Development Mechanism
3	Government support	GOV	The main body of innovation is enterprises, but the government often provides guidance and management for innovation activities through policies, funds, and organizations; the proportion of science and technology expenditures in fiscal expenditures is used to measure the intervention of local government behavior in innovation activities.
4	Open to the outside world	OPEN	Foreign investment increases funds for innovation activities, and the introduction of technology can have a technology diffusion effect; it is measured by the amount of foreign direct investment and converted according to the average price of the annual currency exchange rate.
5	Environmental regulation	ENV	Environmental regulation can guide the development of green innovation activities, but too harsh environmental regulation may occupy the funds of innovation activities
6	Economic development	GDP	The degree of regional development is measured by GDP per capita, and the economically developed places may provide the original driving force for innovation activities in many aspects, such as technology and manpower.

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Table 3. Explanation of the Main Variables and Their Statistical Properties

Variable Name	Measurement Method	Symbol	Unit	Mean	Standard Deviation	Minimum Value	Maximum Value
Green innovation efficiency	Green innovation efficiency value	-	-	0 .5586	0 .1913	0.2198	1
Carbon finance development	Carbon reduction per unit of GDP	CG	Tons/million yuan	1.1083	0 .5762	0 .1960	3.2788
Government support	Science and technology expenditure/fiscal expenditure	GOV	%	3.0941	1.5959	0.8079	6.7569
Open to the outside world	Foreign direct investment /GDP	OPEN	%	1.0432	14126.06	564.9366	78619.91
Environmental regulation	Government spending on environmental protection	ENV	yuan	2.84e+09	2.66e+09	4760000	1.42e+10
Economic development	Regional GDP per capita	GDP	yuan	73291.91	33140.95	30497	187526

The selection of indicators is shown in Table 2. Since the data related to CDM project transactions have not yet been released, and considering the availability of data, the time frame of the study is set as 2012-2021, and the 15 provinces mentioned above are the research objects. Relevant data are obtained from China Statistical Yearbook and provincial statistical yearbooks (Table 3).

5.2. Tobit Modeling

The efficiencies measured by the SBM model are all greater than 0, which is typical of truncated-tailed data and not suitable for regression by ordinary least squares. Therefore, the Tobit panel regression model with the restricted distribution of the dependent variable was chosen:

$$y^{*}=\begin{cases} 0 \\ X_i\beta+\mu_i, c1<y_i^{*}<c2 \\ y_i, y_{i>0} \end{cases} \quad (3)$$

In the above equation,X_i is the explanatory variable and β is the regression coefficient. X_i is the explanatory variable, β is the regression coefficient, y_i is the actual dependent variable, y_i* is the potential dependent variable, and u_i is the random error term. In this paper, we construct a Tobit model with green innovation efficiency as the explanatory variable and multivariate variables as follows:

$$\rho_{it}=\beta_0+\beta_1 CG_{it}+\beta_2 GOV_{it}+\beta_3 OPEN_{it}+\beta_4 ENV_{it}+\beta_5 GDP_{it}+\varepsilon_{it} \quad (4)$$

In the above equation, the subscripts denote the 15 sample regions; the subscript t denotes the time from 2012 to 2021; ρ is the value of green innovation efficiency; CG, GOV, OPEN, ENV, GDF are the explanatory variables; and εit is the random error term.

5.3. Empirical Results and Analysis

The model will be biased if there is multicollinearity among variables. Using the most commonly used formal diagnostic method of variance inflation factor (VIF) test, it is found that the VIF of each variable is much less than 10, and the average value of the VIF test is 1.69, which can ignore the effect of multicollinearity, as shown in Table 4.

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Table 4. Variance Inflation Factor Test

Variable	VIF	1/VIF
GOV	2.49	0.401937
CG	1.83	0.547271
GDP	1.47	0.678828
OPEN	1.46	0.682641
ENV	1.21	0.825897
Mean VIF	1.69	

After that, the Tobit panel regression was performed with Stata16.0 software, and the results are shown in Table 5. The empirical results show that the coefficient of carbon emission reduction per unit of GDP is negative and passes the 1% level test, indicating that the carbon financial market based on CDM project transactions fails to enhance the efficiency of local green innovation activities; the low-carbon technology transfer of CDM projects fails to realize the value of guiding green innovation. The coefficients of local government support and opening up to the outside world both show positive values and pass the significance test, which fully demonstrates that local governments have attached great importance to scientific and technological investment and economic development. At the same time, local governments have played an important role in attracting external funds to promote green innovation activities, showing their positive role in promoting sustainable development. However, the coefficients of environmental regulation and economic development are significantly negative, indicating that environmental regulation, economic development and green innovation have not reached the state of co-development.

Table 5. Tobit Panel Regression Results for Sample Areas from 2012 to 2021

Variable	Correspondence Coefficient	Coefficient Estimates	Standard Deviation	T-value	P-value
c	β0	.5103549	.0726106	7.03	0.000
CG	β1	-.0513139	.0425592	-1.21	0.0230
GOV	β2	.0440345	.0135741	3.24	0.001
OPEN	β3	7.37e-06	1.57e-06	4.68	0.000
ENV	β4	-4.09e-12	4.29e-12	0.342	-1.26e-11
GDP	β5	-1.31e-06	.0726106	-2.15	0.033

5.4. Robustness Tests

Robustness test based on variable substitution. Industry is a high-carbon emitting sector, and CDM projects are mainly carried out in the industrial sector. If the CDM projected carbon emission reduction supported by the industry is more, it is equivalent to a larger amount of carbon trading in the carbon market and a higher level of carbon finance. Therefore, the ratio of regional CDM expected annual carbon emission reduction to industrial value added is used as a new variable to replace the previous variable CG, which has a similar meaning. The regression results are shown in Table 6, and the direction and significance of the coefficients in the model results are basically consistent with those in the previous article, and the model has good robustness.

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Table 6. Tobit Panel Regression Results with Variable Substitution for Sample Areas from 2012 to 2021

Variable	Correspondence coefficient	Coefficient estimates	Standard deviation	T-value	P-value
c	β0	.4626987	.0632643	-1.95	0.000
CG	β6	-.0015318	.0007866	-1.21	0.054
GOV	β2	.0512103	.0118958	4.30	0.000
OPEN	β3	7.23e-06	1.57e-06	4.75	0.000
ENV	β4	-2.98e-12	4.29e-12	-0.71	0.478
GDP	β5	-1.49e-06	4.77e-07	-3.12	0.002

6. Conclusion and Suggestions

6.1. Conclusion

This paper adopts the super-efficient SBM model and uses Matlab to measure the green innovation efficiency values of 15 provinces related to CDM projects, and then empirically examines the impact of carbon finance on green innovation efficiency with the help of the Tobit model. The following main conclusions are drawn:

(1) By measuring the green innovation efficiency values of 15 provinces, this paper finds that the green innovation efficiency values of most provinces are increasing year by year. The average green innovation efficiency value is basically greater than 0.5. This indicates that these economic agents are efficient in utilizing resources in their production and innovation activities and are able to strike a good balance between economic development and environmental protection. This not only reflects the efficient allocation of resources in economic activities, but also shows the positive efforts of enterprises in promoting environmentally friendly innovation.

(2) CDM projects have a significant negative impact on green innovation efficiency. While CDM (Clean Development Mechanism) project transactions should theoretically drive green innovation efficiency, this may not be the case in practice. In fact, the impact of CDM projects on green innovation efficiency may be constrained by a variety of factors. For example, factors such as technical difficulties that may be encountered in the implementation of the project, disturbances in the flow of funds and instability in the policy environment may adversely affect green innovation efficiency. In addition, CDM projects that focus too much on short-term emission reductions and neglect long-term sustainable development may also have a negative impact on green innovation efficiency.

(3) Examine the factors that exert a positive influence on green innovation. First, government funding and policy inclination can stimulate the innovation vitality of enterprises. Government funding provides additional R&D funding for enterprises, which helps to alleviate the financial pressure on enterprises in the process of green innovation. This enables enterprises to focus more on the R&D and application of green technologies, thus promoting the development of green innovation. Through policy support, the government has incentivized enterprises to enhance their investment in the research, development and application of green technologies, a move that will undoubtedly have a positive effect on promoting the development of green innovation. Secondly, the introduction of foreign capital after the opening up of the region can make up for the capital gap in innovation investment. The opening up of the region can attract more foreign capital and technology into the region, thus increasing the sources of capital and technical support for green innovation. The introduction of foreign capital and technology can not only provide more innovation resources and opportunities for local enterprises, but also promote the technological level and innovation ability of local enterprises through the technology spillover effect. Third, environmental regulation fails to strengthen the level of

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green innovation. Environmental regulation also plays an important role in strengthening the level of green innovation. However, if the enforcement and supervision of environmental regulations are not strict enough or if there are loopholes in the regulatory system, enterprises may adopt coping strategies, such as rent-seeking behaviors, to avoid environmental regulations instead of truly engaging in green innovation, thus failing to truly take advantage of environmental regulations. Therefore, the establishment of a more comprehensive and robust environmental regulatory system is crucial to ensuring the quality and efficiency of green innovation. Fourth, economic development has shown a negative impact on green innovation, mainly because economic development relies on high-pollution and high-emission manufacturing industries, and relies on high-pollution and high-emission manufacturing industries as the engine of economic growth, although it can bring about rapid development for a certain period of time, this model of development, which prioritizes the long-term at the cost of the environment, will ultimately result in ecological harm and resource depletion. Moreover, the improvement of the living standards of the population and the pursuit of material enjoyment require more resources, which reduces the efficiency of green innovation activities.

6.2. Suggestions

Based on the above analysis and conclusions, the following Suggestions are given.

(1) Under the current economic and social development trend, economic and social development is no longer an isolated process. It is closely linked to science and technology and innovation, and the ability and level of green innovation of enterprises, as an important main body of economic activities, is directly related to the development potential of a region or even a country. Therefore, local governments need to deeply recognize the role of scientific and technological progress in promoting productivity, so as to pay enough attention and attention to green innovation, which is not only a prejudgement of the future development trend, but also a positive response to the reality of the challenge; In order to effectively promote green innovation in enterprises, we must further increase our support to stimulate their innovative vitality. To this end, the Government should actively increase funding for green science and technology innovation and, through the formulation and implementation of relevant policies, guide enterprises in their transition towards green development. Specifically, the government can, according to the specific situation and needs of different enterprises, formulate targeted, operationally strong tilting policies, such as tax incentives, financial subsidies, etc., so as to encourage and guide enterprises to embark on the road of green transformation, so that enterprises actively engage in green technological innovation.

(2) The rational introduction of foreign investment is an indispensable part of local development strategies. With the deepening of globalization, the inflow of foreign capital has become an important driving force for the economic development of many places. These foreign investments not only bring in a large amount of capital, but also provide local enterprises with advanced technology and management experience. Especially when these foreign enterprises introduce new technologies, they also introduce green innovation concepts and practical experience. Through this spillover effect of foreign technology, it can effectively promote the enhancement of the technical level and innovation ability of local enterprises, and through cooperation with foreign-funded enterprises, local enterprises can learn from their advanced environmental protection technology and experience to make themselves more competitive in the market.

(3) Strengthening environmental regulation is not a quick fix; it needs to be based on scientifically rigorous regulation and enforcement. When formulating environmental policies, the government should have a deep understanding of the specific needs of enterprises in production and operation, and introduce practical and feasible measures. At the same time, it should strengthen supervision and enforcement to ensure that environmental policies take

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root and play their proper role, with a view to maximizing the positive impact of environmental regulations on enterprises.

(4) For the manufacturing industry, the search for green technological innovation is a necessary path. While pursuing economic benefits, enterprises must bear in mind the importance of environmental protection and must not adopt practices that sacrifice the environment in order to reduce costs. Local governments, as an important force in environmental regulation, should especially increase their supervision of heavily polluting enterprises and implement strict management measures. The government needs to be committed to controlling pollution at the source, rationalizing the allocation of production resources and improving the overall efficiency of green development. Only in this way can the quality of the environment be improved in a sustained manner, while at the same time providing enterprises with a healthier and more sustainable external environment.

Overall, in the process of promoting the development of green innovation, governments, foreign investors and enterprises all play important roles. They need to form a strong synergy and work together to optimize the policy environment and standardize environmental regulations in order to improve the overall efficiency of green innovation. Only with the concerted efforts of all parties can we ensure that green innovation will maximize its effectiveness in future development and contribute to the sustainable development of society.

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