Impact of Corporate Green Innovation on Carbon Emission Efficiency based on Carbon Emission Policies

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Abstract: - The issue of climate warming, resulting from elevated carbon emissions, has emerged as a crucial concern for the survival and progress of humanity. Achieving the "dual-carbon" objective necessitates the utilization of technological advancements. This study aims to theoretically investigate the mechanisms through which green technological innovation influences firms' carbon emissions, focusing on the perspectives of industrial restructuring and reducing carbon emission intensity. This research intends to employ the SBM model using provincial panel data spanning from 2017 to 2022, focusing on the regional level in China. Additionally, this study examines the temporal and spatial changes of the variable under investigation and employs the two-way fixed effect model for conducting econometric research. This paper uses the methods of literature analysis, principal component analysis, regression analysis, heterogeneity analysis, and benchmark regression analysis to deeply analyze the development status of green technological innovation in the classification of resource-based cities and low-carbon development demonstration cities in China and to identify the existing problems. The research findings indicate that implementing significant green technology advances can result in a notable increase in the carbon emissions of organizations. Even with this, the impact on strategic green technology developments is not statistically significant in many rigorous tests, including altering explanatory factors, using shorter periods, and doing tail-shrinking tests. Additionally, the presence of heterogeneity is taken into account. The impact above plays a crucial part in the economic development of our nation. The empirical analysis reveals that the process of enhancing carbon emission reduction efficiency in China is significantly influenced by upgrading industrial structure and reducing carbon emission intensity. Building upon this finding, policy recommendations are proposed to guide China in implementing green technological innovation.

Key-Words: - carbon policy, green innovation, carbon efficiency, heterogeneity analysis, SBM model.

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1 Introduction

Global warming and its associated consequences, including but not limited to El Niño, droughts, and species extinction, have emerged as the foremost peril to the long-term viability of the human species and the promotion of sustainable progress on a global scale, [1].

Global climate change is a serious issue currently facing us, and carbon emission policies play a crucial role in mitigating climate change. Carbon emissions mainly come from human activities, such as burning fossil fuels, industrial production, and deforestation. These activities release a large amount of greenhouse gases, leading to issues such as rising Earth temperatures, increasing extreme weather events, and rising sea levels. The need to put in place workable and efficient safety measures has increased due to a variety of issues. To minimize carbon emissions using market mechanisms, such as taxing carbon emissions or introducing carbon trading systems, the establishment of carbon pricing is supported. In addition to reducing reliance on fossil fuels and lowering carbon emissions, this can also encourage businesses and individuals to adopt more environmentally friendly practices, invest in and support renewable energy sources like solar and wind, establish and enforce energy efficiency standards, and encourage industries and individuals to adopt more energy-efficient machinery and technologies. Because forests are significant carbon sinks, maintaining and reforesting them can help absorb carbon dioxide and slow down the rate of climate change. As a worldwide concern, climate change calls for cooperation from all nations. Through international cooperation, technology, and

experience sharing, and the development of more comprehensive and well-coordinated carbon emission rules, nations should work together to solve climate change. Policies aimed at reducing carbon emissions contribute to maintaining ecosystems, reducing the rate of climate change, and ensuring the sustainable growth of human society. As a result, all nations' governments, corporations, and people must seriously consider this issue and implement workable solutions.

In order to achieve carbon neutrality and peak, it is crucial to develop novel green technologies, [2]. These technological advancements could help promote ecological civilization while meeting the urgent needs of modern society. As such, they have significant practical ramifications, [3]. In light of this, two fundamental approaches address the issue. There is a significant focus on the critical technology of peak carbon, which involves extensive research and development efforts to explore innovative solutions for achieving peak carbon and carbon neutrality, which is intended to facilitate the adoption of scientific and technological innovations related to peak carbon and carbon neutrality within industries and enterprises, while also promoting the efficient integration and optimization of resource allocation, [4].

Green technical innovation pertains to developing and implementing technological advancements that prioritize environmental conservation and ecological preservation. The primary objective of such invention is to safeguard the environment, achieve resource equilibrium, and preserve economic progress, [5]. In contrast to conventional technological advancements, green technological innovation possesses distinct attributes, specifically, its emphasis on ecological value, its prioritization of sustainable development, and the intricate interplay of various system elements, [6]. Green technical innovation has a crucial role in providing necessary support for national carbon policies, influencing the overall carbon emissions and intensity at a national level. Most current research emphasizes many factors, including technological innovation, and considers diverse forms of carbon regulations. However, further investigation is required to establish additional mechanisms and empirical examinations of their impact. To achieve this objective, the present study examines the following questions: What is the amount of carbon emission efficiency in China's provincial-level regions? Can implementing green technology innovation lead to enhanced carbon emission efficiency inside enterprises? In what ways can the author improve the carbon emission efficiency of firms through the implementation of innovative green technologies? The primary objective of this project is to elucidate the process through which green technology innovation influences carbon emissions, with a specific focus on optimizing industrial structure and reducing carbon emissions, [7]. The carbon emission efficiency of local regions is analyzed using provincial panel data from 2017 to 2022. This analysis uses the super SBM model, which allows for examining the geographical and temporal evolution patterns of carbon emission efficiency in provincial areas. This project aims to employ a fixed-effects model to systematically explore the impact of green technology innovation by Chinese companies on the carbon emission efficiency of Chinese companies. The analysis will be conducted at the fundamental and strategic levels to provide relevant policy recommendations.

Implementing green technological innovation is paramount in effectively managing overall carbon emissions and attaining the "dual-carbon" objective of advancing economic and social development while safeguarding the environment, [8]. This approach is considered the sole means by which the advancement of ecological civilization may be fostered. Given the context above, it is imperative to undertake a comprehensive investigation into the effects of green technology innovation on the low-carbon economy of urban areas in China, owing to its remarkable academic and practical implications. The execution of this project has the potential to serve as a foundation for decision-making processes aimed at advancing the harmonized growth of "green technology innovation" and "low-carbon economy" in China. Furthermore, it can guide various areas in formulating distinct policies for reducing carbon emissions.

2 Research Hypothesis

Green technological innovations include technologies such as low-carbon technologies and clean energy. Based on the difference in innovation drivers, the innovation drivers of enterprises can be categorized into substantive and strategic. Among them, substantive refers to technologies and techniques that align with ecological principles and laws and can realize actual energy saving and emission reduction, [9]. On the other hand, strategic refers to a kind of innovation aimed at obtaining government subsidies and preferential returns, which is relatively easier. Empirical results show that substantive green technology innovation can significantly contribute to reducing carbon

emissions, rather than strategic-level green technology innovation. On this basis, an undesirable output, carbon emissions, is measured to analyze the differences in the impacts of substantive and strategic green innovations on carbon emissions, as well as their effects on carbon emissions in terms of promoting industrial structure upgrading and reducing carbon emission intensity.

2.1 Green Technology Innovation Promotes Carbon Emission Efficiency through Upgrading the Industrial Structure

The integration of technological innovation plays a crucial role in facilitating the advancement of China's industrial framework and significantly impacting the country's economic progress. Green technological innovation enables the streamlining and improvement of industrial design, hence fostering the enhancement of industrial facilities, [10]. This paper discusses the application of new technologies in reducing resource consumption, particularly regarding energy and raw materials. It also explores the potential benefits of integrating human capital and means of production to enhance overall resource efficiency. Building upon these ideas, the paper introduces a novel development concept that focuses on optimizing the allocation of production factors. The objective is to maximize production efficiency within each industry and improve.

In contrast, it employs energy-saving, emission-reducing, and other environmentally friendly technologies to renew and innovate manufacturing processes and equipment, thereby promoting environmental protection. Encourage enterprises to transition from the conventional labor-intensive, single-production mode characterized by high pollution and energy consumption to a comprehensive service mode that is capital- and technology-intensive, low in energy consumption, and high in value-added. This transition aims to enhance the production process's energy efficiency, cleanliness, and innovation, thereby promoting the deep processing of existing products to increase their added value and achieve product upgrading, [11]. Simultaneously, it can generate correlation effects on both upstream and downstream sectors, bolster the resilience of the current industrial chain, prolong the industrial value chain, and achieve an advanced industrial structure. In the context of China, it can be observed that there exists a negative correlation between the scale of industrial production and carbon emissions. Specifically, as the scale of industrial production increases, there is a corresponding decrease in carbon emissions. Furthermore, more extensive industrial facilities tend to exhibit greater levels of carbon emission efficiency.

2.2 Green Technology Innovation Improves Carbon Efficiency by Reducing Carbon Intensity

Carbon intensity refers to the carbon emissions resulting from the realization of one unit of economic efficiency. It refers to the ratio of total carbon emissions to the total output of the local economy. Carbon emission efficiency refers to GDP as the expected output, while carbon dioxide emissions are a composite indicator of undesired production and, therefore, negatively correlated with carbon emission intensity, [12]. Most of this comes from energy used in business activities and the generation of various wastes. Fossil energy sources, mainly coal, oil, and gas, have considerable pollution and carbon emissions. Depending on the waste generated, the trash can also be categorized as primary, secondary, etc.

The innovation of green technology, fuel ratio optimization, iterative decarbonization pretreatment technology, etc., has optimized carbon reduction by reducing energy consumption from the source. At the same time, it can also be used to increase the emission devices at the online end to reduce the productive carbon emissions during the production process. In addition, the reuse of primary and secondary waste can also contribute to the reduction of final carbon emissions so that the economic benefits obtained can be maintained, based on which the carbon dioxide emissions can be further reduced to improve the efficiency of carbon emission issues, [13]. On the other hand, the primary and secondary waste generated throughout the production process can be recycled and reused to achieve the purpose of the production cycle so that the trash can be resourceful, that the efficiency of the comprehensive utilization of resources can be better improved, so that the original carbon emissions can be reduced or maintained at the same time, to obtain more economic benefits, which can reduce carbon emission intensity.

Based on the above analysis of the mechanism of action, the following hypotheses were proposed in this study:

- Research Hypothesis 1: Green technology innovation of enterprises can improve the carbon emission efficiency of enterprises.
- Research Hypothesis 2: The impacts of two types of green technology innovations, strategic and practical, on the carbon emission efficiency of enterprises, are different.

- Research Hypothesis 3: Green technology innovation can improve the carbon emission efficiency of enterprises by upgrading industrial structures.
- Research Hypothesis 4: Green technology innovations increase carbon efficiency by reducing carbon intensity.

3 Research Design

3.1 Sample Selection and Data Sources

(1) Defined benefit model

A fixed-effects model is proposed, which can better deal with missing variables due to individuals, time, and other factors, which is shown in equation (1).

$$CEE_{it} = \beta_0 + \beta_1 GTI_{it}(LnGTIP_{it}, LnGTA_{it}) + \beta_2 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Among them CEE_{it} is the effectiveness of carbon emissions, an explanatory variable; GTI_{it} green technological innovations, a core explanatory variable. The number of green patent applications ($GTIP$) and the number of utility novelty patent applications (GTA) were selected and measured from both the practical and strategic perspectives; $Control_{it}$ represent a set of controllable variables, which includes the economic standard, technological inputs, and population density; μ_i represents the effect of the individual, which does not change over time; λ_t represents the timeliness, which does not change with individuals; is a random disturbance term; represents the effect of individuals, which does not change over time, and represents the effect of the individual, which does not change over time. ε_{it} represents individual effects that do not change over time, means timeliness that does not change with individuals, and is a random disturbance term.

(2) Super-efficient SBM model

Assuming the existence of n active DMUs and setting P as the output probability, P can be expressed as equation (2).

$$P = \{(x, y) \mid x \geq \sum_{j=1, j\neq k}^{n} X_{ij}\lambda_j, y \geq \sum_{j=1, j\neq k}^{n} Y_{rj}\lambda_j, \lambda \geq 0\} \quad (2)$$

Considering the non-desired output, the model can be described as equation (3):

$$\varphi^* = \min \frac{1 + \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{ik}}{1 - \frac{1}{s_1 + s_2}(\sum_{r_1=1}^{s_1}(s_i^+ / y_{rk}) + \sum_{r_1=1}^{s_2}(s_i^{b-} / b_{ik}))} \quad (3)$$

Based on the environmental equation, the SBM model with non-desired output characteristics is selected by taking human, capital, and energy consumption as input factors and GDP and carbon emissions CEE_{it} as expected outputs (Table 1).

Table 1. Carbon emission efficiency measurements

First-class	Category b	Three-tier
Throw oneself into	Labor power	A person employed in a trade or profession
	Principal	$K_t = I_t + (1-\delta)K_{t-1}$
	Energy consumption	Total energy consumption
Expected outputs	Gdp	Total gdp per year
Non-expected outputs	Carbon footprint	Annual carbon emissions

Four factors were selected for this study, namely: level of economic development, population density, government investment in science and technology, and foreign investment, and they are listed in Table 2 (Appendix).

Energy efficiency: Energy is China's largest carbon emissions source. However, the current coal-dominated energy structure and utilization still need to be more crude, leading to a tremendous waste of energy resources and environmental pollution. Improving energy efficiency is the key to addressing future energy security and climate change, [14]. The author takes the development of clean energy and improvement of energy efficiency as a prerequisite, improves the electrification level, promotes the low-carbon and efficient use of energy, improves energy efficiency under the same energy demand, and reduces energy consumption and carbon emissions under the same economic output. On this basis, China's energy consumption proportion to GDP is analyzed. Regarding the configuration of industries, there has been a decline in the share of national revenue and labor force attributed to the primary sector, alongside a simultaneous increase in the prominence of the secondary and tertiary sectors, [15]. The rational arrangement and optimization adjustment of the industrial structure hold significant practical importance in facilitating the transformation and advancement of China's high-

carbon industry, fostering the growth of the low-carbon sector, enhancing resource utilization, and promoting regional energy conservation and emission reduction. This endeavor carries crucial theoretical significance and application value. Population density: In the process of urbanization, changes in population density will have a direct impact on energy utilization, transportation, infrastructure, and the living environment, thus indirectly affecting CO2 emissions. Concentration of population and productive activities can reduce duplication of construction, increase the proportion of mass transit, increase resource utilization, and reduce CO2 emissions. Still, it can also increase population density and the intensity of economic activity.

3.2 Descriptive Statistics and Smoothness Test

This empirical analysis will utilize panel data from 15 provinces (cities) in China from 2017-2022. The data sources for this study include the China Carbon Accounting Database, the China Energy Statistics Yearbook, the National Bureau of Statistics, and several Chinese governmental offices. Table 3 (Appendix) presents the descriptive statistics of a variable wherein the observed values amount to 350.

To avoid "pseudo-regression," this paper adopts the LLC test, ADF unit root test, and other methods to verify whether each panel data is smooth (Table 4). The study results show that all the samples have been tested to be significant and soft and can be used for deeper modeling.

Table 4. Unit root test

Variant	Adf statistic	P-value	Llc statistic	P-value	Reach a verdict
Cee	4.6821		-14.6259		
Lngtip	15.1284		-21.7362		
Lngta	11.0496		-25.7332		
Lngdpa	5.2493	0.0000	-13.9245	0.0000	Smoothly
Lnpd	-4.1732		-1.6349		
Lnse	13.4935		-4.7362		
Lnfdi	1.3842		-3.2846		
Ts	4.4934		-5.2931		
Cei	5.3492		-6.4382		

3.3 Correlation Analysis

This project presents a quantitative assessment approach for evaluating the extent of innovation in green technology, the level of industrial structure, energy efficiency, per capita gross national product (GNP), population density, and environmental legislation. During the initial research phase, the author discovered a positive correlation between carbon emission efficiency and factors such as green technology innovation, industrial structure, energy efficiency, economic development level, and population density. Conversely, a negative correlation was seen between carbon emission efficiency and environmental regulation. Subsequently, a correlation model was constructed to ascertain the primary determinants of green technology innovation in urban areas of China, followed by an analysis of the directionality of these components.

Then, based on this theory and combined with existing research results, further analysis was conducted on many issues contained in this theory, and relevant concepts were clearly defined. Then, based on the perspective of new economic geography and combined with China's national conditions, construct a low-carbon development strategy suitable for China's national conditions. This project takes "dual carbon" as the starting point and conducts systematic theoretical and empirical research on resource-based cities and low-carbon development demonstration cities in China. Through the research of this project, we aim to reveal the prominent problems and key factors in the "dual carbon" process of resource-based cities and low-carbon development experimental areas in China, and propose corresponding countermeasures and suggestions based on this. Taking the western, eastern, and central regions of China as examples, we apply the relevant theories and methods of New Economic Geography, adopt qualitative and quantitative analysis methods, and from the perspective of time and space, on this basis, A systematic study of the benefits of green technology innovation and carbon emissions in three regions of China, east and west. Using different regions of China as samples and relevant theories and methods of new economic geography, this study explores the differences in green technology innovation and carbon emissions efficiency that are suitable for China's national conditions. Afterward, comparative analysis, and evaluation of the green technology innovation and carbon emissions status in different regions are conducted. And on this basis, propose low-carbon development strategies that are suitable for China's national conditions. To provide scientific theoretical and policy basis for promoting the smooth progress of the "dual carbon" process. By using methods such as literature analysis, principal

component analysis, regression analysis, heterogeneity analysis, and benchmark regression analysis, this paper deeply analyzes the development status of green technology innovation in China's classification of resource cities and low-carbon development of demonstration cities, identifies the problems, and proposes relevant policy recommendations based on this. From three aspects: the influencing factors of green technology innovation, carbon emission policies, and carbon emission efficiency, this study aims to reveal the level of green technology innovation and carbon emission efficiency in different regions of China. Then, at the national and regional levels, a systematic summary was made of several prominent issues that have emerged in China's "dual carbon" construction. On this basis, relevant policy recommendations are proposed.

4 Empirical Results

4.1 Benchmark Regression

Table 5 (Appendix) presents the findings of the baseline regressions, with columns 1 to 3 representing the strategic individual fixed effects of the superficial green technological innovation model, the two-way locked effects model, and the fixed two-way impact mixed with control variables, respectively. The substantive model of personal fixed effects in green technology innovation, the two-way lock-in effects model, and the two-way directed products combined with control variables are represented in columns 4 through 6, respectively. Upon careful examination of columns 1 to 2, it becomes evident that, following the adjustment for individual effects, the coefficient of the impact of strategic green technological innovation on carbon dioxide release efficiency is 0.03249. The statistical significance of the outcome is evaluated at a significance level of 5%. However, including the concept of "time-locking" demonstrates that implementing strategic green technical innovation does not yield a substantial enhancement in carbon emission efficiency.

The findings indicate that, with a confidence level of 10%, the implementation of green technological innovation has a substantial positive impact on the carbon emission efficiency of urban areas. Green patent applications are commonly used to assess engagement in green innovation endeavors. The presence of green technology patents indicates the extent of technological innovation undertaken by a company in the realm of environmentally sustainable production. Implementing novel technologies, processes, and equipment can enhance production efficiency and resource allocation efficiency within an enterprise. Consequently, this optimization can positively impact the enterprise's human capital and the structure of inputs and outputs. Ultimately, these improvements contribute to an overall enhancement in the enterprise's production and resource output efficiency. Subsequently, the carbon emission efficiency of the firm is enhanced. The enhancement of green innovation signifies a notable trajectory in the nation's pursuit of studying and implementing low-carbon science and technology. The organization employs cutting-edge energy storage technology, sustainable and renewable energy sources, environmentally friendly production methods, research and development in environmental preservation, and the construction of zero-carbon buildings. These efforts aim to expedite the advancement of crucial core technologies, facilitate the growth of leading industries, and enhance the efficacy of energy and resource utilization. This proposal seeks to promote the transition of conventional endeavors and subsequently foster the advancement of a range of strategic emerging initiatives. The objective is to propel China's manufacturing sector towards a shift from low-end to high-end production, which entails leveraging advantageous resources, collaborating to achieve breakthroughs in crucial core technologies, extending the industrial economic chain, enhancing the value-added of products, and effectively driving the development of a green, low-carbon economy.

Furthermore, this approach seeks to enhance the efficacy of carbon emission reduction efforts within the region. In general, the advancement of green technology to stimulate increased investment and related factors serves as an input variable. The outcomes of low-carbon innovation have the potential to generate scale effects using the aggregation and spillover effects, which facilitates the achievement of transformation and application objectives. Additionally, it enables the exchange and sharing of innovation factors across various industries. The transition from labor-intensive, resource-based industries to technology-based sectors can be realized by leveraging knowledge-intensive industrial transfers. Consequently, a shift from a "high carbon" urban development model to a "low carbon" one is proposed, thereby promoting cities' coordinated green and low-carbon development.

Nevertheless, when considering the implementation of "time-locking," it becomes evident that the efficacy of strategic green technology innovation in enhancing carbon emission efficiency is limited. One potential explanation is that purposeful and straightforward green technical innovation primarily involves strengthening the structure and integrating the aesthetics of existing products, resulting in a simplistic design approach. The application process's duration is significantly shorter compared to the implementation of substantial green technology innovations. The absence of assistance in the current production process results in a negligible effect on the emissions of solid carbon dioxide. The coefficient of influence of green technological breakthroughs on CO2 emissions has been examined in Column 5, revealing a statistically significant value of 0.0384 at a significance level of 5%. Based on the findings shown in Column 6, it is evident that including various control factors has resulted in an impact coefficient of 0.0249 for meaningful green technological innovation on carbon emissions. Simultaneously, it satisfies the 10% significance threshold, suggesting that green technical improvements have a statistically significant impact on enhancing carbon emission efficiency. The research findings indicate a positive correlation between the implementation of practical green technological innovation and the extent of improvement in carbon emission efficiency. Specifically, the study reveals that for every unit rise in practical green technological innovation, there is a corresponding increase in carbon emission efficiency by 2.49%. The research above findings validate the first hypothesis, which posits that implementing green technology innovation has the potential to enhance the carbon emission efficiency of firms. The conclusion above aligns with the findings in columns 1-3, indicating that substantial green technical innovation positively impacts carbon emission efficiency. In contrast, strategic green technological innovation does not yield the same effect. The study above provides evidence supporting hypothesis 2, which posits a disparity in carbon emission efficiency between the "practical" and "substantive" forms of green technology creation.

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positive and significant correlation has been observed between China's urban energy utilization efficiency and carbon emission efficiency. China's industrial energy usage constitutes around 65% of the overall energy consumption within society. However, concurrently, the energy and industrial sectors of the country exhibit significant carbon emissions. Hence, the mitigation of carbon emissions in energy production, the expeditious substitution of fossil energy sources with cleaner alternatives, and the augmentation of their proportion in overall primary energy consumption are advantageous in reducing carbon emissions and alleviating environmental pollution. In contrast, energy efficiency can be seen as an indicator of technical advancement, as advancements in complex technology (such as low-carbon energy efficiency) and soft technologies (such as management systems) for reducing carbon emissions contribute to enhanced efficiency. In the process of urbanization, population density directly impacts public transport, resource utilization, and the sharing of pollution and emission reduction facilities, and this impact is a double-edged sword. On the one hand, the scale and agglomeration effects of increasing population density prompt the gathering of high-level production factors and high-quality talents, which in turn promotes the low-carbon transformation of cities, accelerates high-quality development, improves energy utilization, and further enhances their carbon dioxide emission reduction efficiency, [16]. At the same time, with the rapid accumulation of population, too much population will lead to problems such as ecological environment deterioration, traffic congestion, and building carbon emissions. On this basis, this paper proposes a new research idea. A discernible inverse relationship exists between environmental regulation and the effectiveness of carbon emission reduction. Specifically, as the level of ecological law decreases, the intensity of carbon emission reduction increases. Consequently, enhancing environmental regulations will facilitate the advancement of pollution mitigation and emission reduction in a mutually reinforcing manner. Environmental law is the principal policy instrument for promoting ecological environmental protection and fostering an economy focused on low-carbon development. It achieves this by establishing a scientific and practical system of carbon dioxide emissions standards through legal and administrative means. This system targets industries with high energy consumption and increased emissions, effectively curbing their carbon emissions. Consequently, it accelerates eliminating outdated production capacity, encourages the adoption of a green industrial structure, reduces carbon content, and enhances product quality. In contrast, implementing carbon taxation, providing low-carbon subsidies, and utilizing other mechanisms motivate corporations to engage in technical advancements and allocate more investments towards environmentally friendly and low-carbon technology. Enterprises are compelled to develop and use energy-saving and low-carbon technologies and efficiency-enhancing equipment to facilitate the adoption of cleaner production practices within their operations.

Currently, China is vigorously promoting high-quality economic development in the process of implementing the "dual carbon" goals. However, in this process, we have also encountered some new problems. We must fully recognize the multifaceted issues that exist in the process of environmental regulation and urbanization, and the positive effects of different measures in promoting carbon reduction. This is a response to climate change, sustainable development in economic and social development, and a need to promote national economic and social development. The goal of regulating the environment should be to achieve a "win-win" situation in developing a low-carbon economy and protecting the environment. To achieve this goal, it is necessary to improve from the following aspects: firstly, strengthen the policy guidance for green industry and optimize the allocation of green industry; The second is to promote energy conservation, reduction, and reconstruction in relevant industries. Thirdly, we need to strengthen guidance and support for low-carbon technologies, such as clean production, circular economy, and environmental protection industries; The fourth is to conduct beneficial exploration on "green finance".

4.2 Heterogeneity Analysis

From the above, green technology innovation can effectively improve carbon emission efficiency, which is a stable and reliable result. China has been piloting carbon emissions trading since 2011, and there are apparent differences between pilot and non-pilot provinces regarding resource endowment, economic development, and scientific and educational development levels. To study this policy, Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei, and other countries were selected as pilot countries, other countries were selected as non-pilot countries were chosen as non-pilot countries, and regions were selected as references. They were selected as non-pilot

countries, [17]. In the pilot provinces and cities, green technological innovation is still an effective way to promote carbon emission reduction, and the results show that the influence coefficient of each factor is 17.3%, which is qualified by a 5% significance test.

Green technology innovation plays a crucial role in improving the carbon emission efficiency of enterprises, and in-depth research is conducted on the specific impact of different green technology innovations on carbon emission efficiency. Through empirical research and data analysis, quantify the carbon emission reduction effects of various green technologies in different industries, and provide more specific guidance for enterprises in technology selection and implementation. In addition to carbon emission efficiency, research should also focus on the impact of green technology innovation on corporate economic performance. This includes the effects of cost reduction, market competitiveness improvement, and sustainable operation, providing a more comprehensive evaluation for enterprise decision-making. Enterprises analyze the dissemination and impact of green technology innovation throughout the entire supply chain, understand the actual effects of applying green technology in procurement, production, and sales, and optimize the carbon emission efficiency of the entire value chain, Simultaneously examine the promoting effect of carbon emission policies in different countries and regions on green technology innovation in enterprises. At the same time, pay attention to factors such as policy uncertainty and support, analyze the impact on green technology innovation in enterprises, and provide a reference for the government to formulate more effective policies.

This result indicates that the improvement in carbon emission efficiency in pilot provinces and cities is mainly due to the balanced contribution of various factors, rather than the dominant role of a specific factor. Heterogeneity analysis further reveals the possible diversity between pilot provinces and cities. This heterogeneity may stem from factors such as different industrial structures, energy combinations, and policy implementation effects in different regions. For example, some regions may focus more on promoting renewable energy technologies, while others may place more emphasis on improving energy efficiency and introducing carbon capture technologies. This in-depth heterogeneity analysis provides important references for future carbon trading policies and green technology innovation. Policymakers can adjust policy directions based on the characteristics of different regions, encourage more targeted green technology innovation, and achieve more effective carbon reduction and sustainable development nationwide (Table 6).

Table 6. Heterogeneity test

	1	2
Factor	Pilots	Non-pilot
Lngtip	0.173**	0.0409
	-0.0547	-0.0141
GDPA	4.77e-05*	6.81e-05***
	(2.83e-05)	(1.71e-05)
SE	1.72E-06	-3.38e-08
	(2.83e-05)	(2.24e-07)
FDI	-1.26e-04	-2.81e-04**
	(7.11e-05)	(1.12e-04)
PD	-7.38e-04	-0.00191
	(4.82e-04)	(0.00183)
Constant	-0.0204	1.055**
	(0.386)	(0.339)
Fixed time	Be	
Individual fixation	Be	
Control variable	Be	
Observed value	100	250
R-squared	0.782	0.385

Through empirical analysis, analyze the impact of green technology innovation in various regions of China on regional economic development. Using fixed effect models and bidirectional fixed effect models, regression analysis was conducted on the eastern, central, and western regions. Based on the above tests, all regression results from the three major regions were selected as the analysis objects (Table 6). Research has found that the carbon emission efficiency of cities in eastern China is significantly positively correlated with the level of economic development. The results indicate that this method has a significant positive effect on carbon emissions in the central region of China. But in the western region, these negative effects have not reached a significant level. The eastern region has a favorable economic environment, an open policy environment, more scientific research institutions, and a better research environment, which can attract more professional talents and strengthen the application of low-carbon technology research and development. Promoting the development of high-tech industrial clusters plays a crucial role in adjusting industrial structure and improving energy efficiency. Among these factors, innovation is the most important; central China, has strong labor market competitiveness and can also accept industry and technology transfer from the East. However, the synergistic effect between green technology innovation and enterprise emission reduction is very

weak, and enterprises lack incentives for green and low-carbon technology research and development. The effect of innovation on reducing carbon emissions is not significant, and it has not passed significance testing. Due to the low level of economic development in the western region, as well as the inadequate research environment and infrastructure, investment in environmental protection technology research and development is relatively low. In these regions, although some cities have relatively high levels of economic development, many regions have relatively backward industrial structures, and excessive energy consumption has led to environmental pollution during economic development. The development of energy and raw material industries has also had a huge impact on the environment and resources. Therefore, from a national perspective, each region should formulate corresponding energy-saving and emission-reduction policies based on their own actual situation. The development of green technology in China has not achieved significant results in reducing carbon emissions, which to some extent limits the development of green technology in China; In addition, some regions have energy and raw material industrial bases, and economies dominated by energy and raw materials account for a large proportion in the heavy chemical industry. In some cities, the economy has already experienced a recession, cities are shrinking, and talent is being lost. When enterprises are developing green and environmentally friendly products, through research, we can see that in some places, our research and development costs are relatively high, but in high-tech industries, our green technology innovation can greatly improve our carbon emission efficiency.

At the same time, we must also recognize that in the long run, green technology innovation plays an important role in emission reduction, but the effectiveness of this role also depends on China's resource allocation. Overall, there are significant differences in economic development, environmental protection, and low-carbon technological innovation among different regions in China. Therefore, various regions in China should formulate corresponding policies based on their own national conditions to promote their low-carbon development. The biggest problem in China currently is energy conservation and emission reduction, and to solve this problem, we must start from two aspects: technological innovation and industrial structure adjustment. Therefore, it is necessary to strengthen technological innovation, optimize industrial and energy structures, leverage high-tech advantages, and promote the green and low-carbon development of traditional industries, as well as the transformation and upgrading of the circular economy.

5 Results and Discussion

This study aims to comprehensively examine the impact of China's green technology innovation on its carbon emission efficiency, employing both theoretical and empirical approaches. This study examines the carbon emission efficiency of different inter-provincial regions in China throughout 2017-2022. The findings reveal distinct spatial variations in the Yangtze, Pearl, Beijing-Tianjin-Hebei, and Qinghai regions. The implementation of green technological innovation has the potential to enhance firms' carbon emission efficiency significantly. This positive impact is primarily observed in important green technological innovations, whereas strategic technological innovations do not exhibit the same influence. The conclusions above were derived via a sequence of rigorous robustness tests. The author's analysis of heterogeneity reveals a notable disparity between the degree of green technological innovation and the level of carbon emission efficiency in China's pilot regions to reform the country's carbon trading system. Conversely, the disparity between these two factors is not statistically significant in non-pilot areas. Building upon these findings, the author proposes policy recommendations to enhance industrial structure and reduce carbon emission intensity. The results of the research yield the subsequent observations:

Local governments and enterprises should actively facilitate the advancement of green technological innovation. This can be achieved by augmenting the allocation of national scientific research funds, establishing a dedicated fund specifically for green technological innovation, and determining research and development priorities as well as critical directions to enhance innovation in green technology. By implementing a strategy that integrates industry and education, the government can guide and support enterprises in green technology innovation. This can be achieved through a collaborative effort involving university research and development, enterprise demand, and targeted financial assistance. Such measures aim to mitigate uncertainties faced by enterprises and enhance their motivation to innovate in green technology. Ultimately, these initiatives seek to elevate The amount of green technology innovation among firms in China has been examined in [18].

Conversely, it is imperative to prioritize industrial output and enhance firms' innovative capacity in green technology. Incorporate low-carbon and clean energy technology throughout the production process to improve the environmental sustainability of products. The objective is to enhance the economic benefits by increasing the value added to current developments and optimizing the utilization of waste resources. This approach aims to achieve carbon dioxide emission reduction, facilitate China's low-carbon transformation, and ultimately improve the country's carbon emissions efficiency.

By implementing strategies to optimize the industrial structure, it is possible to enhance carbon emission efficiency and effectively utilize its intermediary function. The implementation of green technology innovation has the potential to facilitate the enhancement of industrial structures. Hence, the research conducted in this paper aims to enhance the efficacy of carbon emission reduction efforts in China. Thus, governments worldwide should develop and promote green technology and boost the optimization of the industrial structure to make it more reasonable and high-end to play a more effective role. On the one hand, enhancing the resilience of the current industrial chain and expanding its reach to both upstream and downstream industries can facilitate the extension and supplementation of the present industry. Additionally, fostering inter-industry collaboration, promoting the rational allocation of resources across sectors, and implementing other measures can contribute to rationalizing the industrial structure and enhancing resource allocation and utilization efficiency.

Consequently, these efforts can lead to a more effective reduction of carbon dioxide emissions. In contrast, local governments can leverage the resource advantages inherent in their regions to facilitate the transition of regional industries from labor-intensive to technology-driven, capital-based models. Additionally, they can encourage companies to evolve from solely production-oriented entities to comprehensive consulting-based enterprises, thereby fostering the development of a high-end industrial structure. Simultaneously, the iterative optimization of existing technologies within the industry will contribute to the augmentation of product value, bolstering their overall market competitiveness. This optimization will also establish a basis for attaining more substantial economic benefits, ultimately enhancing the efficiency of carbon emission reduction.

6 Conclusion

The realization of carbon peaking and carbon neutrality is a universal, extensive, fundamental, global, and comprehensive transformation. With the achievement of the "dual carbon" goal, China's traditional high-input and high-emission economic growth model is shifting towards a high-quality growth model driven by technological innovation. This project will analyze the spatiotemporal evolution of green technology innovation and carbon emission efficiency in China from the perspective of economic geography, establish an analysis framework for its influencing factors, reveal its mechanism of action, and based on this, combine with the actual situation in China to propose corresponding policy recommendations. There are still shortcomings in the research content and methods of this paper, which need to be further improved in the future. The content of future research should be further strengthened at the policy level, and quantitative methods should be further developed at the methodological level.

Due to significant differences in geographical location, economic growth, industrial structure, and technological principles among different regions, it is necessary to select typical regions for empirical research, comprehensively evaluate their level of green technology innovation and carbon emissions, and propose corresponding countermeasures and suggestions accordingly.

Against the backdrop of carbon emission policies gradually becoming an important factor in the business environment of enterprises, this study analyzes the relationship between green innovation and carbon emission efficiency in enterprises. Under the guidance of carbon emission policies, enterprises actively engage in green innovation, which has a significant positive impact on improving carbon emission efficiency. By introducing more environmentally friendly and low-carbon production technologies and management models, enterprises can reduce carbon emissions, improve resource utilization efficiency, and achieve a win-win situation of economic and environmental benefits. It is impossible to overlook how carbon emission regulations encourage green innovation in businesses. Businesses are compelled to go toward a more sustainable development path by government regulations and limits on carbon emissions. During this process, businesses not only look for technological innovations to break new ground, but they also modify their operations and management to comply with carbon emission regulations. Green innovation is rarely instantaneous, though, and businesses may experience challenges and financial

strain during the transition. Therefore, by offering pertinent policy assistance and lowering innovation costs, the government and society should encourage businesses to actively engage in green innovation and better adapt to the requirements of carbon emission rules. As a result, green innovation has a favorable effect on carbon emission efficiency in businesses that are governed by carbon emission rules. In addition to helping businesses stay competitive in the market, this also helps society as a whole meet sustainable development targets and lessen the negative environmental effects of climate change. Thus, it is essential to promote and motivate businesses to use green innovation in accordance with regulations pertaining to carbon emissions.

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Conflict of Interest

The author has no conflicts of interest to declare.

APPENDIX

Table 2. Impact factors

Name (of a thing)	Methodologies	Modes of influence
Economic development	Per capita gdp	There is a close correlation between the level of economic development and the environmental protection input factor cee gdp in China. There is a positive link between the desired level of economic growth and carbon emission efficiency.
Population density	Number of people in the area	Population density is closely related to human capital, which is a factor of investment in environmental protection, but the higher the population density, the more likely it is to cause an increase in productivity, which in turn causes a rise in carbon emissions, which in turn causes a fall in carbon emissions.
Science and technology	Science and technology expenditures	Investments in science and technology r&d can promote technological innovation, and thus productivity, and therefore carbon efficiency in enterprises.
Foreign investment	Investors	On the one hand, foreign investment can promote economic development by injecting capital and optimizing the investment structure so the author can reduce carbon dioxide emissions more effectively. On the other hand, it improves China's energy conservation and emission reduction level by studying and learning advanced technology abroad.

Table 3. Descriptive statistics

Variant	Effective value	Average value	(statistics) standard deviation	Minimum value	Maximum values
Cee		0.824	0.249	0.499	1.439
Lngtip		6.284	1.738	0	10.347
Lngta		6.394	1.624	0.628	10.276
Lngdpa		10.473	0.647	8.394	12.044
Lnpd	350	5.493	1.284	2.031	8.236
Lnse		12.839	1.349	8.933	16.244
Lnfdi		6.219	1.432	1.924	9.842
Ts		1.183	0.346	0.138	2.017
Cei		0.044	0.013	0.017	0.134

Table 5. Benchmark regression

	1	2	3	4	5	6
Factor	Individually	Bi-directionality		Individually	Bi-directionality	
Lngta	0.03249**	0.00765	0.00863			
	(0.00458)	(0.02486)	(0.02148)			
Lngtip				0.0173***	0.0384**	0.0249*
				(0.00573)	(0.0204)	(0.0172)
GDPA			5.17e-04***			4.73e-05***
			(1.34e-04)			(1.48e-05)
SE			1.78e-06			1.24e-07
			(1.07e-06)			(1.24e-07)
FDI			-1.84e-04*			-1.48e-05
			(9.86e-04)			(9.76e-06)
PD			-0.000132**			-9.73e-04*
			(5.17e-06)			(4.87e-04)
Constant	0.746***	0.739***	0.738***	0.748***	0.547***	0.372**
	(0.0438)	(0.173)	(0.186)	(0.0437)	(0.174)	(0.173)
Fixed time	Clogged	Be	Be	Clogged	Be	Be
Individual fixation			Be			
Variant	Clogged	Clogged	Be	Clogged	Clogged	Clogged
Effective value			350			
Coefficient of determination	0.073	0.081	0.17	0.086	0.138	0.386

*Note: ***, **, and * represent 1%, 5%, and 10% significance levels, respectively.*