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The Spatial Analysis of the Role of Green Finance in Carbon Emission Reduction

Menghan Xiao [1], Xiaojing Guo [2], Gonghang Chen [1,*], Xiangfeng Ji [1,*] and Wenqing Sun [1]

[1] School of Business, Qingdao University, Qingdao 266071, China; 2018200705@qdu.edu.cn (M.X.); sunwenqing323@foxmail.com (W.S.)
[2] Shandong Guangxinda Asset Evaluation and Project Management Corporation, Qingdao 266000, China; guoxiaojing0204@126.com
* Correspondence: chengonghang762@gmail.com (G.C.); jixiangfeng@qdu.edu.cn (X.J.)

Abstract: Under the "dual carbon" goal, the core issue at present is to improve the environment while ensuring economic development. As a result, green finance, that is a tool that integrates finance and environmental protection, has shown increasingly significant carbon reduction effects. With the panel data of 30 provinces in China from 2012 to 2021 being the research object, this study employs a spatial Durbin model to examine the impact of green finance on carbon emissions and further discusses its mechanism effects. The empirical results indicate the following: firstly, the development of green finance effectively suppresses carbon emissions; secondly, by decomposing the spatial effect of green finance on carbon emissions, it is found that green finance also reduces carbon emissions in neighboring regions due to the spillover effects; finally, green finance can suppress carbon emissions through technological innovation and industrial structure upgrading. Therefore, it is imperative to actively engage in practical work related to green finance, to establish a sound system for green finance, and simultaneously, to enhance cooperation among regions in terms of green finance, in order to fully leverage its role in suppressing carbon emissions.

Keywords: green finance; carbon emissions; spatial analysis; mediation analysis

Citation: Xiao, Menghan, Xiaojing Guo, Gonghang Chen, Xiangfeng Ji, and Wenqing Sun. 2024. The Spatial Analysis of the Role of Green Finance in Carbon Emission Reduction. *Risks* 12: 138. https://doi.org/10.3390/risks12090138

Academic Editor: Rüdiger Kiesel

Received: 30 June 2024
Revised: 16 August 2024
Accepted: 21 August 2024
Published: 29 August 2024

1. Introduction

Since the reform and opening up, while the economy in China has experienced a rapid growth, the operation of high-input, high-energy-consuming, and low-efficiency enterprises have also caused a sharp increase in carbon dioxide emissions. According to the International Energy Agency (IEA), China became the world's largest carbon emitter in 2009, and these emissions continue to grow (Zhao et al. 2022).

In September 2020, General Secretary Xi Jinping made it clear at the United Nations General Assembly that China would strive to achieve the historical peak of carbon dioxide emissions before 2030, which set the target of reaching the peak of carbon emissions. The peak of carbon emissions refers to the process where the annual carbon dioxide emissions of a region or industry reaches its highest historical value. It is the historical inflection point of carbon dioxide emissions from increase to decrease, that is, the apex of the parabola. Meanwhile, China also aims to be carbon-neutral by 2060 (Jung et al. 2021). Hereinafter, this is referred to as the "dual carbon" target. In the report of the 20th National Congress of the Party, it is pointed out that "we must actively and steadily promote carbon reduction to achieve carbon peak and carbon neutrality". In recent years, China's economy has been changing in the direction of high quality, and the goal of "dual carbon" has also attracted more and more attention. Carbon reduction is the key strategic direction in China's ecological civilization construction during the "14th Five-Year Plan" period (Wang et al. 2021). At the same time, to ensure the steady growth of the economy, a low-carbon economy has been the main development goal in recent years (Fu et al. 2021).

A low-carbon economy can achieve the goal of low consumption, low emissions, and high efficiency without giving up economic development, which is a new economic development model (Ji et al. 2021). However, most of the carbon emissions come from industrial enterprises nowadays, and it is not the best choice to blindly suppress some industrial enterprises for the purpose of carbon reduction. To cope with this challenge and the accompanying increasingly severe environmental risks, more and more countries have pledged to develop their green economy. A green economy brings new energy to sustainable development with possibilities to solve the bottleneck which exists in practice. The green economy reflects the concept of ecological civilization, pursuing the harmony and win–win situation of the economic growth and environmental protection (Loiseau et al. 2016). Finance is the core tool of modern economic development, and green finance is an important tool to promote the development of a low-carbon economy and realize economic transformation. Finance guides the flow of capital and adjusts the coordination of resources in the process of economic development, which is an important means to spur China to achieve high-quality development (Ali et al. 2022; Tsoukala and Tsiotas 2021). Green finance is the core driving force of sustainable economic development. A green finance market is a type of financial market, mainly in the form of green loans and green bonds, aiming to promote green and low-carbon development and environmental protection. A perfect green financial market can guide the flow of capital to low-carbon and green projects with its power, so as to achieve the "dual carbon" goal (Zhang 2011). The "dual carbon" goal poses new challenges to the development of green finance in China (Cai et al. 2023). The government, enterprises, and research institutions constantly explore and innovate green finance (Rehman et al. 2022). Therefore, as a populous country with the highest carbon emissions, can the development of green finance effectively reduce carbon emissions? What is the intrinsic mechanism of its effects?

This paper aims to examine how green finance promotes China's carbon emission reduction from an endogenous perspective. Accordingly, this paper can contribute to the literature through the following aspects: (1) Using China's provincial panel data from 2012 to 2021, this paper empirically verifies the above inhibitory effect of green finance on carbon emissions with a spatial analysis, providing experience for the development of China's green finance market in environmental pollution. (2) It verifies the internal mechanism of the impact of green finance on carbon emissions from the aspects of technological innovation and industrial institutions and puts forward targeted suggestions according to the conclusions, so as to contribute to the realization of the "dual carbon" goal. The "dual carbon" goal aims to achieve both "carbon peak" and "carbon neutrality" as part of the national strategy to mitigate carbon emissions. (3) Suggestions are put forward to strengthen the development of green financial technology and improve financial markets and policies, so as to further improve the green financial system under the "dual carbon" goal. In contrast to previous studies, the unique features of this paper lie in the mediation effect analysis between green finance and carbon emissions, while some studies like Jiang et al. (2020) did not analyze this. Moreover, this paper selects different mediation variables to study the interaction between green finance and carbon emissions, which is different from Zhang et al. (2024). Another feature is the selection of the spatial weight matrix, which not only considers the economic level of each region but also combines the distance factors. This makes the research more practical than Su et al. (2024).

The remainder of this paper is organized as follows. Section 2 presents the literature review. Section 3 presents the theoretical hypotheses. Section 4 presents the empirical model and the data used. Section 5 analyzes the empirical results, followed by the conclusions and suggestions in Section 6.

2. Literature Review

2.1. Financial Development and Carbon Emission

The relationship between finance and carbon emissions has increasingly become the focus of global research, as financial behavior and policies have important effects on climate

change mitigation and promoting sustainable development. This paper reviews the links between finance and carbon emissions, including the impact of financial markets on carbon emissions, and the role of financial policies and tools in controlling carbon emissions. As for the impact of financial markets on carbon emissions, one view is that the development of a region's financial industry and the improvement in its economic level depend on the consumption of resources, thus increasing the regional carbon emissions (Dogan and Seker 2016). The development of finance and the economy worsens the environment and increases carbon emissions (Chen et al. 2023). For example, the development of national finance makes it easier for people to apply for personal loans from banks, which is more conducive for consumers to buy more houses, air conditioners, cars, refrigerators, and so on (Sadorsky 2010). These products increase carbon emissions. Another view is that the development of finance can reduce carbon emissions. On the one hand, financial development can increase the consumption of green and low-carbon products and thus promote a relative reduction in carbon emissions. On the other hand, the financial market has a direct impact on the carbon emission behavior of enterprises by providing capital and investment channels. Governments and financial regulators can use financial means to encourage companies to reduce their carbon emissions.

2.2. Green Financial Development and Carbon Emissions

Since then, with the improvement and promotion of green-finance-related policies, its concept has become more and more specific, and the research on it has become more and more comprehensive. Under the current "dual carbon" target, the global research on green finance also focuses on its impact on carbon emissions. Green finance refers to the financial industry, taking environmental sustainability and low-carbon development as the core goals of economic development, and strengthening the financing and investment of environmental protection projects and green economy projects through the support and guidance of financial institutions and market tools for sustainable development. Khan et al. (2018) used different methods to analyze data from different countries and obtained financial conditions on carbon emissions. The financial sector is able to steer financial flows in line with a low-carbon economy, which plays an important role in decarbonizing the global economy (Ozili 2022). The traditional high-carbon economy has been transformed to a low-carbon economy, and the mode of economic development has also changed, which progressively transforms traditional finance into green finance too (Li et al. 2022).

However, previous researchers have used traditional financial development indicators, which do not allow the exploration of how green finance suppresses carbon emissions. Green credit is a major policy innovation that promotes the transformation of the economic development mode and industrial green transformation. Therefore, researchers have begun to pay attention to the impact of some green financial instruments, such as green credit and green investment, on carbon emissions that can explain green financial indicators. Shi et al. (2022) studied the impact of green credit on investment behavior, and the study showed that green credit could regulate the flow of capital, so that energy-saving and environmental protection enterprises had more financial support. Su and Lian (2018) believes that green credit and green venture capital, which is a type of financial capital services to invest in environment-oriented companies, can provide green enterprises with more financing, thus incentivizing them to direct this financing to low-carbon products or services, so as to produce more advanced low-carbon products and provide better services. Rasoulinezhad and Taghizadeh-Hesary (2022) showed that green bonds were a suitable method to promote green energy projects and reduce carbon emissions significantly. Bakry et al. (2023) took 76 developing countries as an example to show that developing green finance could reduce carbon emissions. Soundarrajan and Vivek (2016) discussed the trends, the future opportunities, and challenges in green finance in emerging India. Affected by factors such as geographical location and economic development degree, the development degree of green finance in different regions is also different, which makes the effect of green finance in different regions on carbon emissions also different (Wang et al. 2021). Xu et al. (2023)

confirmed that issuing green bonds and green economic growth could accelerate the green economic growth rate and develop a digital green financing market. In order to achieve long-term outcomes in reducing carbon emissions, enhancing renewable energy development and investing in green finance are two critical tools (Li and Umair 2023).

3. Theoretical Hypotheses

Research shows that the development of green finance can significantly reduce energy consumption, effectively adjust the industrial structure, and thus promote the development of green innovation. However, few scholars have studied how green finance can directly reduce carbon emissions. Generally speaking, research is carried out through the impact mechanism between green finance and carbon emissions. This paper analyzes the impact mechanism from the following three types.

The first is that green finance can provide financing channels for low-carbon enterprises. Green financial products (such as green credit) can provide resource allocation through financial institutions, rationally allocate funds from the supply and demand sides in the market, accelerate industrial upgrading and transformation, and restrict access to capital for some traditional industries with high carbon emissions and high energy consumption (Wang et al. 2021). Financial institutions can try to introduce third-party guarantee institutions to create credit for new green enterprises and solve the problem of long-term financing difficulties (Liang et al. 2021). Polukhin et al. (2019) showed that green funds could be guided to low-carbon, energy-saving, and environmentally friendly green industries, and green government guidance funds could be set up to attract social capital investment and promote green insurance business.

The second is that green finance can provide an orderly carbon finance market. The current system and policies of green finance include the carbon trading system, carbon emission standards, and so on, which are being improved step by step. The diversification of policies and systems is conducive to market standardization and industrial transformation and upgrading, and provides an orderly green financial market for the low-carbon economy (Umar et al. 2021). A green credit evaluation system can be established to obtain, identify, and classify enterprise information, manage post-loan, and strengthen the mechanism construction of the risk management process (Yin et al. 2019). Although China's carbon trading market is still in its infancy, the future development prospect of the carbon trading market is huge (Ren et al. 2020).

The third is that green finance can influence the low-carbon economy by providing technical support. Green finance technology innovation will broaden the application of new digital technologies in the field of green finance and can provide the appropriate technical support to facilitate the realization of the "dual carbon" goal. Green finance technology innovation is based on blockchain, cloud computing, and other technologies to provide more guarantees for carbon emission data collection and improve the efficiency of green finance services. Green finance can promote enterprises to strengthen green technology innovation, turn to low-carbon production of products, and reduce ineffective supply, thus accelerating the transformation and upgrading of enterprises (Zeng et al. 2022). Green finance provides financial support for environmental protection activities to promote the introduction of low-carbon technology innovation into green enterprises (Wang and Yang 2020).

In summary, the impact of green finance on carbon emissions can be realized through the above three aspects, so the first hypothesis can be obtained as follows:

Hypothesis 1. *Green finance can inhibit interregional carbon emissions.*

Green finance uses green credit, green investment, and other financial instruments to provide financial support for enterprises to carry out green technology innovation through financing support and financing constraints (Hu et al. 2021). For heavy industries with high carbon emissions, technological innovation can promote the development of clean energy technologies, thus reducing the carbon emissions generated in energy production

(Qin et al. 2018). Green technology innovation can achieve the sustainable development of the environment through energy conservation and emission reduction (Braun and Wield 1994). In conclusion, this paper proposes that green finance can inhibit carbon emissions by promoting the green technology innovation of enterprises. Thus, this study makes the following hypothesis:

Hypothesis 2. *The influence mechanism between green finance and carbon emissions can be transmitted through green technology innovation, that is, green technology innovation has an intermediary effect.*

By implementing differentiated lending policies, the green financing market raises the financing threshold of high-emission enterprises, increases the financing pressure, and urges enterprises to adjust their industrial structure (Shi et al. 2022). Irfan et al. (2022) showed that the upgrading of the industrial structure was affected by the development level of green finance. The higher the development level of green finance, the faster the transformation and upgrading of the industrial structure, so as to restrain regional carbon emissions. With the development of green financial market, China's industrial structure is constantly inclined toward the tertiary industry, traditional industries relying on coal energy gradually lose their price advantage, and emerging industries with low carbon emissions and environmental protection have greater development potential, forming a virtuous cycle. To sum up, the third hypothesis can be obtained as follows:

Hypothesis 3. *The influence mechanism between green finance and carbon emissions can also be transmitted through the industrial structure, that is, the industrial structure also has an intermediary effect.*

4. Empirical Model and Data Explanation

4.1. Sample Selection

4.1.1. Explained Variable: Carbon Emissions

The study selected the carbon emission intensity of the region as the measure of regional carbon emissions (CEE). Due to the lack of direct publication of carbon emission data in China's Energy Statistical Yearbook and significant differences in regional economic development levels among Chinese provinces (Zhang et al. 2020), this paper adopted the calculation standards released by the Intergovernmental Panel on Climate Change (IPCC) to calculate the carbon emissions generated by per unit output in each region. The specific calculation formula is as follows:

$$CEE = \frac{C}{GDP} = \frac{\sum_{n=8} E_n \cdot CCF_n \cdot CEF_n \cdot CMF}{GDP}, \quad (1)$$

where CEE is the index of carbon dioxide emissions; E_n denotes the consumption of class n fossil fuels; CCF_n and CEF_n refer to the carbon standard and coal coefficient of class n energy, respectively; CMF is the weight ratio of carbon atom to carbon dioxide, that is, 12/44. E_n indicates the top eight energy sources with high carbon dioxide emissions, which are coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, and natural gas.

4.1.2. Core Explanatory Variable: Green Finance

The core explanatory variables are the four main indicators representing the development of green finance: green credit, green securities, green investment, green insurance. Referring to the green financial measurement system established by Jiang et al. (2020), the weights of the above four indexes were assigned by the entropy method, which constitutes the comprehensive index of green finance.

For the measurement of green credit, this paper adopted two indicators, the proportion of new bank loans of A-share-listed environmental protection enterprises and the proportion of interest expenses of high-energy-consumption industries, as positive and

negative indicators, respectively (Mashud et al. 2021). For the measurement of green securities, this paper adopted the two indicators of A-share-listed environmental protection and the proportion of market value of enterprises with high energy consumption as positive and negative indicators to measure green securities (Zhang et al. 2022). The green insurance index includes two indicators: the proportion of agricultural insurance scale and the proportion of agricultural insurance compensation. Since green insurance is not clearly defined, and the most affected by the natural environment in China is agriculture, these two indicators were used as positive and negative indicators to measure green insurance (Mishra et al. 2021). For the measurement of green investment, this paper selected the proportion of provincial fiscal expenditures on energy conservation and environmental protection in the total fiscal expenditures and the proportion of investment in environmental pollution control in GDP to measure green investment (Li et al. 2021). The details of the green finance development index is summarized in the following Table 1.

Table 1. Details of green finance development index.

Secondary Indicators	Third-Level Indicators	Index Description
Green credit	Proportion of new bank loans of A-share-listed environmental protection enterprises	New bank loans for A-share-listed environmental protection companies/loans from A-share-listed companies to banks
	Proportion of interest expense of high-energy-consumption industry	Interest expense of six high-energy-consuming industries/total industrial interest expense
Green securities	Proportion of market value of listed enterprises	Market value of A-share-listed environmental protection enterprises/market value of A-share-listed enterprises
	Proportion of market value of enterprises with high energy consumption	Market value of A-share-listed high-energy-consuming enterprises/market value of A-share-listed enterprises
Green investment	Proportion of agricultural insurance scale	Agricultural insurance income/property insurance income
	Proportion of agricultural insurance claims	Agricultural insurance expenditures/agricultural insurance income
Green insurance	The proportion of compensation for environmental pollution control	Environmental pollution control investment/GDP
	The proportion of fiscal environmental protection expenditures	Financial environmental protection expenditure/total financial expenditures

4.1.3. Control Variables

In this paper, five indicators for economic development level, education level, openness to the outside world, energy intensity, and government intervention degree were introduced as control variables to study their impact on carbon emissions.

Level of economic development (PGDP). The natural logarithm of the per capital GDP of each province was used to measure the degree of economic development of each province (Wu et al. 2021). The improvement in the economic development level may make green finance develop better, thus promoting the low-carbon economy. **Level of education (Edu)**. The education level of a region was measured by the number of students in ordinary colleges and universities in the total number of regions. Education level can have an impact on environmental awareness, promote the development of environmental protection technology, and thus affect carbon emissions (Wang et al. 2021). **Degree of openness (Open)**. The ratio of total imports and exports of commodities to GDP was used as an indicator to measure the level of openness. The development of green finance is affected by the level of openness to the outside world, which has an impact on the low-carbon economy. Opening to the outside world is carried out through import and export trade, which produces carbon emissions, so opening to the outside world has a two-way effect on carbon emissions (Sun et al. 2019). **Energy intensity (EI)**. The proportion of energy consumption in the GDP

of each province was used to measure energy intensity. As the main source of carbon emissions, energy consumption has a great impact on carbon emissions (Bianco et al. 2019). **Government intervention (Gov)**. The ratio of local fiscal expenditures to GDP was used to measure the degree of government intervention. Local governments mainly use investment, financial allocation, and administrative policies to guide the development of green technologies and green environmental protection industries, thus affecting the carbon emission efficiency (Xiang et al. 2023).

4.1.4. Mediating Variables

Technological innovation and production structure were selected as the mediating variables affecting the mechanism of green finance and carbon emissions.

Technological innovation (TI). This paper used the proportion of the number of green invention patents granted to the number of patents granted in each province to measure the level of technological innovation in each province Hsu (2016). The green invention patent is better than the green utility patent (green patents are comprised of these two types) in terms of patent quality and energy-saving efficiency, and it was measured by the international patent classification provided by the World Intellectual Property Organization. The progress of science and technology can improve the efficiency of energy use and industrial production efficiency, thus promoting regional carbon emission reduction. **Industrial structure (IS)**. This paper measured the level of industrial structure through the proportion between the output value of the tertiary industry and the output value of the secondary industry. The development of green finance can promote the transformation and upgrading of enterprises to low-carbon industries, thus affecting carbon emissions (Gan and Voda 2023; Zhang et al. 2020).

4.2. Data Description

All the selected data in this paper were from the Wind database, CNRDS database, *China Statistical Yearbook*, *China Energy Statistical Yearbook*, and provincial statistical yearbooks. Some missing data were supplemented by an interpolation method. Descriptive statistics of the variables are provided in Table 2.

Table 2. Descriptive statistical analysis.

Variable	N	Mean	S.D	Min	Max
CEE	300	0.893	0.926	0.064	4.380
GF	300	0.767	0.0648	0.642	0.899
PGDP	300	9.225	0.381	8.504	10.32
Edu	300	0.602	0.118	0.363	0.896
Open	300	1.372	1.336	0.050	5.672
EI	300	0.251	0.103	0.107	0.6435
Gov	300	0.0172	0.0295	0.000186	0.175
IS	300	1.036	0.833	0.00404	6.317
TI	300	0.374	0.146	0.00711	0.687

4.3. Construction of Spatial Weight Matrix

In practical situations, some economic activities in each region are affected by their adjacent areas and also have a certain impact on their adjacent areas, thus producing a spatial radiation effect and a spillover effect. Therefore, this study measured the spatial correlation by constructing a distance matrix and nested matrix combining distance and economics. Among them, the distance matrix was calculated with the inverse of the geographical distance between the provincial areas according to their longitude and latitude coordinates. The distance weight matrix was as follows:

$$W_{ij} = \begin{cases} \frac{1}{d_{ij}}, i \neq j \\ 0, i = j \end{cases}$$

where d_{ij} indicates the geographical distance of the provincial areas.

The geographic weight matrix reflects the influence of geographical location, but due to the development of modern transportation and network technology, the connection between regions is closer and closer. Therefore, the economic distance matrix should be further built to resolve the issues inherent in the distance matrix. That is, the distance matrix ignores the economic and social influence between regions. The economic distance matrix was constructed as follows:

$$W_{jj} = \begin{cases} \frac{1}{|PGDP_i - PGDP_j|}, i \neq j \\ 0, i = j \end{cases}$$

where the $PGDP$ represents the per capital GDP.

Considering the advantages of the above two matrices, this paper further constructed the nested matrix combining distance and economics, which was as follows:

$$W_{jd} = \begin{cases} \frac{1}{|PGDP_i - PGDP_j| \times d_{ij}}, i \neq j \\ 0, i = j \end{cases}$$

The Moran index can be used to detect spatial similarity and spatial dissimilarity between regions, with values between −1 and 1. The positive and negative aspects of spatial correlation between variables is related to the positive and negative values of the Moran index. When the Moran index is positive, it has a positive spatial correlation; On the contrary, when negative, it has a negative spatial correlation. When the Moran index is equal to 0, it indicates that there is no spatial correlation between the variables. Table 3 shows the global Moran index of provincial-level carbon emissions from 2012 to 2021. From Table 3, under the nested matrix combining distance and economics, the Moran index is all positive, and the corresponding P-values are all significant. This shows that the domestic carbon emissions at the provincial level are not randomly distributed, but the carbon emissions between adjacent regions show a similar state, which also means that the selection of a spatial measurement model has a certain rationality and accuracy.

Table 3. Global Moran's I of carbon emission efficiency of 30 provinces in China from 2012 to 2021.

Year	Moran'I	E(I)	sd(I)	z	*p*-Value
2012	0.268 **	−0.034	0.141	2.144	0.032
2013	0.305 **	−0.034	0.145	2.338	0.019
2014	0.298 **	−0.034	0.144	2.304	0.021
2015	0.295 **	−0.034	0.145	2.267	0.023
2016	0.296 **	−0.034	0.146	2.258	0.024
2017	0.301 **	−0.034	0.148	2.264	0.024
2018	0.264 **	−0.034	0.146	2.042	0.041
2019	0.279 **	−0.034	0.146	2.146	0.032
2020	0.281 **	−0.034	0.145	2.170	0.030
2021	0.271 **	−0.034	0.147	2.080	0.037

Note: ** indicate significance at the level of 5%.

4.4. Empirical Model

In order to verify the impact mechanism between green finance and carbon emissions, the following basic model was developed, motivated by the research theories of previous studies.

$$CEE_{it} = \beta_0 + \beta_1 \times GF_{it} + \beta_i \times X_{it} + \alpha_i + \gamma_t + \varepsilon_{it}, \quad (2)$$

where CEE represents the carbon emissions; i denotes the province; t refers to the year; β_0 represents the intercept term; GF is the independent variable, which denotes the development level of green finance; β_1 and β_i refer to coefficients accordingly; X denotes control

variables that affect CEE; α_i refers to individual effect; γ_t refers to the fixed effect of the year; and ε_{it} refers to the random error term.

However, carbon emissions are not only affected by the level of green finance development in a local region, but also by the level of green finance development and the carbon emissions in neighboring provinces. Therefore, this paper adopted the spatial Durbin model to study the impact mechanism between green finance and carbon emissions, because ignoring the spatial correlation may cause an estimation bias in the results. The spatial Durbin model can simultaneously examine the impact of green financial development and carbon emissions in neighboring areas on the carbon emissions in the studied area. This paper established a spatial Durbin model as follows:

$$CEE_{it} = \beta_0 + \beta_1 \times GF_{it} + \lambda_1 \sum_{j=1}^{N} W_{ij} \times CEE_{jt} + \lambda_2 \sum_{j=1}^{N} W_{ij} \times GF_{jt} + \beta_i \times X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (3)$$

where λ denotes the spatial coefficient between the independent variables.

This paper further investigated the mediating effect. In particular, technological innovation and industrial structure were selected as the mediating variables, and the following models were obtained.

$$M_{it} = \delta_0 + \delta_1 \times GF_{it} + \lambda_1 \sum_{j=1}^{N} W_{ij} \times M_{jt} + \lambda_2 \sum_{j=1}^{N} W_{ij} \times GF_{jt} + \delta_i \times X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (4)$$

$$CEE_{it} = \pi_0 + \pi_1 \times GF_{it} + \pi_3 \times M_{it} + \lambda_1 \sum_{j=1}^{N} W_{ij} \times M_{jt} + \lambda_2 \sum_{j=1}^{N} W_{ij} \times GF_{jt} + \pi_i \times X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (5)$$

where M is the mediating variable, representing technological innovation and industrial structure.

5. Empirical Result Analysis

5.1. Benchmark Regression Test

In this paper, the fixed-effect spatial Durbin model was used for the econometric analysis, and the spatial weight matrix was the symmetric nested matrix combining distance and economics. In addition, based on the SDM model regression, the mixed OLS regression and fixed-effect regression results are shown in Table 4.

In the SDM of Table 4, the spatial autocorrelation coefficient of the rho model was −0.194 at the 1% significance level, which indicate that there is a space spillover effect, namely, a province's carbon emissions affect the neighboring province's carbon emissions. It means that the local carbon emissions' increase causes a decrease in the carbon emissions of other regions, verifying that there is an obvious space autocorrelation and space spillover effect between carbon emissions of different regions.

The results of the core explanatory variable green finance (GF) were negative in the three models and were significant at least at the 5% level in both mixed OLS regression and SDM regression, indicating that green finance had a significant inhibitory effect on carbon emissions. From the perspective of the significance level, the SDM model was more significant. Therefore, the results estimated by the SDM model were more accurate. It can be seen from Table 4 that every 1% increase in green finance reduced regional carbon emission intensity by 1.174%. Hypothesis 1 is therefore verified. This is because the development of green finance leads to the corresponding development of low-carbon technologies. At the same time, the development of green finance enables reasonable resource allocation, promoting enterprises to transform to a low-carbon direction, so as to reduce carbon emissions. In the literature, Wang et al. (2022) analyzed the impact of green finance on carbon emissions from the long-term and short-term aspects, and their findings are consistent with the findings here. In addition, Zhang et al. (2024) also proved that

green finance could inhibit carbon emissions, but what they analyzed was green finance agglomeration, which is different from the index in this paper.

Table 4. Benchmark regression test.

Variables	OLS	FE	SDM
GF	−1.746 **	−0.216	−1.174 ***
	(0.770)	(0.306)	(0.402)
PGDP	−0.328	−0.546	−1.560 ***
	(0.303)	(0.619)	(0.342)
Edu	6.838 ***	1.572	−1.258
	(1.200)	(1.112)	(0.901)
Open	−0.584 ***	0.00372	−0.0240
	(0.0802)	(0.0618)	(0.0437)
EI	1.171 **	0.627	0.166
	(0.570)	(0.967)	(0.426)
Gov	−6.563 ***	−2.197	−6.268 ***
	(1.462)	(1.972)	(1.474)
Constant	1.756	5.026	
	(2.793)	(5.789)	
rho			−0.194 *
			(0.114)
sigma2_e			0.0192 ***
			(0.00158)
Observations	300	300	300
R-squared	0.339	0.086	0.065

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Among the control variables, the regression coefficient of the economic development level was −1.560, which indicates that with the improvement in the regional economic development level, the improvement in the environmental quality is paid attention to, so as to promote the carbon emission reduction. This result is consistent with the finding in Chen and Chen (2021). The regression coefficient of the degree of government intervention was significantly negative at the 1% level. That is, the effective intervention of the government inhibited the growth of carbon emissions, because the government could issue carbon emission reduction policies at the macro level and guide the market to develop low-carbon circular development, so as to restrain the growth of carbon emissions. However, the level of education, openness, and urbanization were not significant under the spatial model.

5.2. Spatial Effect Decomposition

This paper decomposed the spatial effect of provincial green finance on carbon emissions and analyzed the direct effect, indirect effect, and total effect between independent variables and dependent variables, as shown in Table 5. Firstly, this paper analyzed the spatial effect of the core explanatory variables; in terms of the direct effect of green finance on carbon emissions, it was significantly negative at the level of 1%, indicating that green finance could inhibit local carbon emissions. This is because green finance promoted the *R&D* investment of enterprises in energy-saving and emission reduction technologies, and promoted the transformation and upgrading of enterprises, so as to reduce carbon emissions. Its indirect effect was also significantly negative at the level of 10%. That is, the improvement in the local green finance level also had an inhibitory effect on the carbon emissions of adjacent areas, which shows that the development of local green finance can drive the development of adjacent areas and play a demonstration role for the neighboring areas. The medium indirect effect between green finance and carbon emissions was stronger than the direct effect, which indicates that green finance affects the carbon emissions of adjacent areas. Therefore, green finance needs to coordinate the development between regions and then play its role in carbon emission reduction. The total effect of green finance was also significantly negative at the level of 1%, which means that the

level of green finance plays a significant inhibitory role in the local and neighboring areas. Therefore, the development of green finance should be encouraged. Yang et al. (2023) showed that green finance would not only have an impact on local carbon emissions but also affect surrounding areas through spatial spillover effects. Results further showed that the coefficient of the direct effect was larger than that of the indirect effect. However, the research in this paper showed that the coefficient of the indirect effect of green finance was higher, because green finance exhibited a more pronounced spillover effect among non-manufacturing enterprises.

Table 5. Decomposition of spatial effects of green finance on carbon emissions.

Variables	LR_Direct	LR_Indirect	LR_Total
GF	−1.095 ***	−1.734 *	−2.828 ***
	(0.409)	(0.958)	(1.089)
PGDP	−1.409 ***	−4.487 ***	−5.895 ***
	(0.328)	(0.848)	(0.835)
Edu	−1.279	2.751	1.472
	(0.905)	(1.936)	(1.534)
Open	−0.0154	−0.275 ***	−0.290 ***
	(0.0424)	(0.106)	(0.106)
EI	0.108	1.662	1.770
	(0.439)	(1.172)	(1.144)
Gov	−5.977 ***	−5.257	−11.23 ***
	(1.446)	(3.553)	(4.052)

Standard errors in parentheses; *** $p < 0.01$, * $p < 0.1$.

5.3. Robustness Test

In order to test the reliability of the above results, the following two robustness test were conducted. First, we replaced the spatial weight matrix. Specifically, this paper replaced the symmetric nested matrix with the asymmetric nested matrix combining distance and economics. Second, we excluded municipalities directly under the Central Government, because these municipalities are particular in their policies; thus, this study excluded Beijing, Tianjin, Shanghai, Chongqing and then performed the estimation. The results are shown in Table 6. It can be seen that the regression coefficient of green finance was significant at the 1% level, consistent with the results in Table 6 for the SDM estimation results. That is, the estimate was robust, and the level of green finance could effectively inhibit carbon emissions.

Table 6. Robustness check.

Variables	Replaced Weight	Excluded Municipalities
GF	−1.186 ***	−1.260 ***
	(0.431)	(0.443)
PGDP	−1.410 ***	−2.039 ***
	(0.366)	(0.378)
Edu	−0.690	−0.174
	(0.801)	(1.219)
Open	−0.0256	−0.0118
	(0.0525)	(0.0630)
Ec	0.264	0.129
	(0.507)	(0.496)
Gov	−4.742 ***	−7.681 ***
	(1.579)	(1.855)
rho	0.0306	−0.260 **
	(0.0700)	(0.113)
sigma2_e	0.0228 ***	0.0198 ***
	(0.00186)	(0.00175)
Observations	300	260
R-squared	0.080	0.025

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$.

5.4. Mediating Effect Test

Table 7 shows that with the nested matrix, industrial structure and technological innovation had mediating effects in the influencing mechanism between green finance and carbon emissions.

Table 7. Mediating effect test.

Variables	IS	TI
GF	−0.956 **	−0.953 **
	(0.390)	(0.399)
IS	0.133 ***	
	(0.0275)	
TI		1.090 ***
		(0.311)
PGDP	−1.676 ***	−1.427 ***
	(0.334)	(0.341)
Edu	−1.183	−0.556
	(0.867)	(0.907)
Open	−0.0444	−0.0373
	(0.0424)	(0.0428)
Ec	−0.328	0.205
	(0.423)	(0.425)
Gov	−5.451 ***	−5.147 ***
	(1.431)	(1.471)
rho	−0.213 *	−0.246 **
	(0.113)	(0.114)
sigma2_e	0.0178 ***	0.0183 ***
	(0.00146)	(0.00151)
Observations	300	300
R-squared	0.093	0.081

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

When industrial structure was used as an intermediary variable, the coefficient of green finance was significantly negative at the 5% level. For the specific industrial structure, Yuan et al. (2016) showed that in the initial stages of economic development, carbon emissions are primarily influenced by the secondary industry, which has a higher energy intensity. As the economy progresses to a certain stage, the service industry gradually becomes the dominant force impacting carbon emissions. The structure of energy-dependent industries was positively correlated with carbon emissions. However, upgrades in industrial production and industrial structure had a negative regulatory effect on the impact of energy-dependent industrial structures, indirectly reducing carbon emissions (Wu et al. 2021). Therefore, industrial structure was one of the mediating variables affecting the mechanism of green finance and carbon emissions, which verifies Hypothesis 2. It shows that the development of green finance makes the enterprises pay more attention to the industrial structure for the formulation of a low-carbon direction to curb carbon emissions. This is because the development of green finance makes capital flow to low-carbon industries, promotes the transformation and upgrading of enterprises, brings about the transformation of the enterprise production mode and technological progress, reduces resource waste and environmental pollution, improves energy utilization, and thus reduces carbon emissions. Su et al. (2024) showed that green finance promoted the transformation and upgrading of industrial structure, thus inhibiting carbon emissions, which is consistent with the conclusions of this paper. However, the mediation effect of technological innovation was not discussed in Su et al. (2024).

When technological innovation was used as an intermediary variable, the coefficient of green finance was significantly negative at the 5% level. Therefore, technological innovation was one of the mediating variables affecting the action mechanism of green finance and carbon emissions, which verifies Hypothesis 3. It shows that the development of green finance can increase the investment in green technology innovation and strengthen research and development, and thus inhibit the improvement of carbon emission intensity. This is because the development of green finance can provide financial support for green technology

innovation, so that enterprises can vigorously develop green innovation technology, and green innovation can reduce the cost of clean energy through technological development, encourage the use of clean energy, and increase the proportion of clean energy in energy, so as to achieve the effect of inhibiting carbon emissions (Ji et al. 2021).

6. Conclusions, Suggestions and Prospects

6.1. Conclusions

This paper analyzed the effect of green finance on carbon emissions and simultaneously discussed the internal mechanism of this effect using the 2012–2021 provincial panel data. Specifically, this paper built indicators to measure the development level of green finance, and used the space Durbin model to analyze the influence of green finance on carbon emissions. The results show that the influence of green finance on carbon emissions had an obvious spatial effect and could effectively curb carbon emissions. After a series of robustness tests, the conclusion was still valid. From the result of the further decomposition of the spatial effect of green finance on carbon emissions, green finance not only suppressed the local carbon emissions but also suppressed the carbon emissions of neighboring areas with the nested matrix combining distance and economics. Finally, this paper studied the mechanism of green finance in affecting carbon emission, and the results showed that green finance could significantly affect carbon emissions through industrial structure transformation and technological innovation channels.

6.2. Suggestions

Based on the above research conclusions, this paper proposes the following suggestions:

Firstly, the green finance market should be improved. The government can expand channels for green financing and increase investment funds for green industries. Thus, low-carbon projects can be developed. The government can also promote the development and innovation of green financial products such as green bonds, green loans, and green funds, and attract more funds to focus on the green sector.

Secondly, policies related to greenness should be improved. The government can develop and implement policies and regulations related to green and low-carbon development and guide financial institutions to further promote green development. The government can also implement green-finance assistance policies tailored to local situations to enhance regulatory oversight of the green finance industry, thereby reducing information asymmetry.

Thirdly, the government can encourage industries to undergo green transformation and upgrading. The government can take measure to promote the guiding role of green finance in the energy consumption structure and green innovation. This can promote the transformation and upgrading of the enterprise energy consumption structure, transforming it into a green and low-carbon production mode. This can also encourage enterprises to develop green industries, improve the level of green technology development, explore the successful transformation of green technology innovation, and help achieve the dual carbon goal.

6.3. Prospects

This paper primarily employed the SDM model to study the relationship between green finance and carbon emissions and concluded that the development of green finance contributed to reducing carbon emissions. Additionally, various methods were employed to validate the effectiveness of the conclusions. However, there was a lack of specific analysis on the impact of different indexes and weights of green finance on how to reduce carbon emissions. In future research, a more detailed and precise discussion on the indexes and weights of green finance could lead to more accurate conclusions and relevant policy recommendations. Moving forward, there are other interesting directions that are worthy of future investigation. For instance, one may use additional techniques, such as principal component analysis (PCA), to perform a validation of the robustness of the composite index weights like green finance. A study with additional variables related to environmental

policies, the demographic structure, and a macroscopic analysis can be conducted to see their effect. The final topic of interest is to analyze variables in depth, for example, how the proportion of green patents and the specific industrial structure of each province affect carbon emissions.

Author Contributions: Conceptualization, G.C. and X.J.; methodology, M.X.; software, M.X. and X.G.; validation, M.X., X.G. and G.C.; formal analysis, X.J.; investigation, X.G.; resources, M.X. and W.S.; data curation, M.X. and W.S.; writing—original draft preparation, M.X. and X.G.; writing—review and editing, G.C.; supervision, X.J.; project administration, X.J. All authors have read and agreed to the published version of the manuscript.

Funding: There was no funding for this study.

Data Availability Statement: Data can be obtained upon request.

Conflicts of Interest: Author Xiaojing Guo was employed by the company Shandong Guangxinda Asset Evaluation and Project Management Corporation. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The Shandong Guangxinda Asset Evaluation and Project Management Corporation had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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