

Original Paper

Research on the Impact of Green Finance on Regional Low-carbon Transformation: An Analysis of the Mediating Effect Based on Green Innovation

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Abstract

Under the background of "double carbon" goal, green finance is an important institutional arrangement to promote green and low-carbon economic transformation. Based on China's provincial panel data from 2006 to 2023, this paper constructs a comprehensive evaluation index of green finance, and uses panel fixed effect model, mediating effect model and instrumental variable method to test the impact of green finance on regional carbon emission intensity. The results show that the development of green finance significantly reduces regional carbon emission intensity, and the conclusion is still valid after robustness test. Green finance reduces carbon emission intensity by increasing the output of green patents, and green innovation plays a complete intermediary role; Heterogeneity analysis shows that the promotion effect of green finance is more obvious in areas with low economic level and after the low-carbon policy node in 2015. This paper provides empirical evidence for improving the green finance policy system and promoting regional differentiated low-carbon development.

Keywords

Green finance, Carbon emission intensity, Green innovation, Regional low-carbon transformation, Mediating effect

1. Introduction

Global climate change is a severe challenge facing mankind. It has become a consensus to reduce greenhouse gas emissions and achieve green and low-carbon development. As the world's largest carbon emitter, China has set a clear goal of carbon peak by 2030 and carbon neutrality by 2060. Low-carbon transformation of the economy involves energy structure, industrial structure and technological progress, which requires a huge amount of funds to support clean energy, industrial green transformation and low-

carbon technology innovation (Wen et al., 2021). As traditional financial funds are difficult to fully cover, green finance, as an institutional arrangement to guide social capital to flow into green and low-carbon areas, is expected to be high.

The core of low-carbon transformation is to reduce the carbon emission intensity per unit of GDP and decouple economic growth from carbon emissions. It is estimated that China needs to invest about 3 trillion to 4 trillion yuan in green and low-carbon sectors every year, which cannot be met by finance alone. In 2016, the People's Bank of China and other seven ministries and commissions issued the Guidelines for Establishing the Green Financial System, which basically established the top-level framework of green finance in China, rapidly expanded the market size of green credit, green bonds and green funds, and set up several national green financial reform and innovation pilot zones (Lv et al., 2025). However, the actual environmental benefits of green finance, especially the impact on regional carbon emission intensity and the transmission mechanism, still need to be further tested. Existing studies mostly focus on macro aggregate or single green credit index (Wen et al., 2022; Shi and Shi, 2022), but lack detailed investigation on the comprehensive level of regional green finance and its impact on carbon emission intensity through technological innovation.

Based on the provincial panel data from 2006 to 2023, this paper constructs a multi-dimensional green finance development index, and systematically examines the impact and transmission mechanism of green finance on low-carbon transformation. The theoretical contribution is to verify the intermediary role of green technology innovation in the impact of green finance on carbon emission intensity, and clarify the path of "green finance → green technology innovation → carbon emission reduction"; It is found that green finance plays a more obvious role in promoting regions with low economic level, showing the characteristics of "increasing marginal effect", and the policy guidance effect is enhanced after the Paris Agreement in 2015. The practical significance is to provide a basis for the design of regional differentiated green finance policies: underdeveloped regions should give priority to expanding the coverage of green finance, developed regions should focus on improving the quality and efficiency, and open up the channels of green technology innovation to promote the transformation of green finance from "total promotion" to "structural optimization."

2. Literature Review

2.1 Measurement and Economic Benefits of Green Finance

Green finance measurement is the basis of empirical research. In the early stage, a single index was used, such as the proportion of interest expenses of high energy-consuming industries and the proportion of loans for energy conservation and environmental protection projects (Song et al., 2021). With the rich connotation, scholars used the entropy method to measure the level of provincial green finance from the dimensions of green credit, green securities, green investment and green insurance (Lee & Lee, 2022; Ren et al., 2020), and some studies added the dimension of carbon finance (Liu, 2025). As for the economic effect, a large number of studies affirm that green finance can optimize the allocation of

resources, guide funds from high-pollution and high-energy consuming industries to green and environmental protection industries, and promote the upgrading of industrial structure. At the same time, it can alleviate financing constraints, reduce information asymmetry, and promote enterprises' green technology innovation (Chen et al., 2021).

2.2 Research on Factors Affecting Carbon Emission Intensity

Carbon emission intensity is the core indicator for measuring the degree of economic development decoupling from carbon emissions. The environmental Kuznets curve hypothesis suggests that there is an inverted "U" relationship between carbon emissions and economic growth. The energy consumption structure is the decisive factor. An energy structure dominated by coal directly leads to high carbon emissions. Optimizing the energy structure and reducing the proportion of coal is the key to achieving carbon reduction (Lin & Zou, 2014). Technological progress is the fundamental driving force for reducing carbon emission intensity. Green technological progress that leans towards energy conservation and emission reduction can improve energy efficiency and promote the substitution of fossil energy by clean energy (Shao et al., 2022). Urbanization, opening up to the outside world, and environmental regulations are also important influencing factors.

2.3 Green Finance, Green Innovation and Carbon Emission

Research placing the three in a unified framework is a frontier in recent years. Theoretically, green finance provides funds for high-investment and high-risk green technological innovation through resource allocation, alleviating the predicament of enterprises "wanting to innovate but lacking funds"; the signaling effect can also attract social capital to pay attention to the green industry. Empirically, Wen et al. (2022) found that green finance improves the quality of economic growth and reduces environmental costs through supporting green innovation; Ran and Zhang (2023) confirmed that green innovation and industrial structure optimization are important channels for green finance to reduce carbon emission intensity. However, some studies have pointed out that the "punishment effect" of green finance may increase the compliance costs of high-carbon enterprises and squeeze out R&D investment in the short term (Lu et al., 2021).

2.4 Critical Review

The existing research still has shortcomings: the measurement of green finance is not unified, and a single indicator is difficult to comprehensively reflect the development level; the transmission mechanism is mostly concentrated on industrial structure upgrading, and the exploration of the intermediary channel of green technological innovation is weak; the endogenous treatment is insufficient, and less use of instrumental variable methods; heterogeneity analysis mostly focuses on the regional level and is less examined on time policy nodes. This paper constructs a multi-dimensional green finance index, measures green technological innovation by the number of green patent authorizations, and uses the mediation effect model and instrumental variable method to systematically test the impact of green finance on regional low-carbon transformation and its transmission mechanism, and conducts heterogeneity analysis based on economic level and policy nodes.

3. Theoretical Analysis and Research Hypotheses

3.1 *The Direct Impact of Green Finance on Carbon Emission Intensity*

Green finance directly affects regional carbon emission intensity through capital allocation effects and industrial guidance effects. On the one hand, policies such as green credit guidance impose financing constraints on high-pollution and high-energy-consuming industries, increasing the cost of funds or limiting the scale of credit, forcing them to reduce scale or upgrade, directly reducing the carbon emissions per unit of output (Su & Lian, 2018). On the other hand, green finance provides preferential financing for low-carbon industries such as energy conservation and environmental protection, supporting their rapid growth and increasing the proportion of low-carbon industries. This "rewarding the good and punishing the bad" mechanism prompts the transfer of production factors from high-carbon sectors to low-carbon sectors, optimizing the industrial structure and reducing regional carbon emission intensity. Thus, it is proposed:

Hypothesis 1: The improvement of green finance development level can significantly reduce regional carbon emission intensity.

3.2 *The Mediating Role of Green Innovation*

Green innovation is the fundamental driving force for achieving a low-carbon transformation, and green finance provides crucial financial support for it. According to the "Porter Hypothesis", designing reasonable environmental regulations can stimulate enterprise innovation and generate an "innovation compensation effect". The mechanisms by which green finance promotes green innovation include: First, alleviating financing constraints. Green technological innovation has a long cycle, high risks, large capital demands, and its outcomes have positive externalities, while traditional financial markets are insufficiently supported. Green loans, green bonds, and green funds specifically provide funds for green projects, alleviating financing constraints and reducing financing costs (Wang & Wang, 2021). Second, signal transmission and risk sharing. Green finance conveys the government's encouragement for green development to the market, enhancing investor confidence and guiding social capital to flow into the green innovation field; tools such as green insurance can disperse technical risks and market risks, increasing the enthusiasm of enterprises for innovation (Zhou et al., 2023). Green innovation reduces carbon emission intensity from the source: green process innovation improves energy utilization efficiency and reduces energy consumption and carbon emission per unit output; innovation in green products will promote a clean and low-carbon energy consumption structure and reduce dependence on fossil energy. Therefore, green finance, by supporting green innovation, fundamentally changes high-carbon production methods and energy consumption structures, and reduces regional carbon emission intensity. Based on this, it is proposed:

Hypothesis 2: Green finance reduces regional carbon emission intensity by stimulating green technology innovation, that is, green innovation plays an intermediary role in the process of green finance affecting carbon emission intensity.

4. Research Design

4.1 Definition of Variables

The explained variable is carbon emission intensity (co2), which is expressed by the total amount of carbon emissions per unit of GDP. After winsorization, it is denoted as co2_w, and the standardized carbon emission intensity (co2_z) is constructed for robustness test. The core explanatory variable is green finance index (gf), which constructs a comprehensive evaluation system from the dimensions of green credit, green bond, green insurance, green investment, green fund, green support and green rights and interests. The entropy method is used to measure the provincial green finance development index, with values ranging from 0 to 1. A higher value indicates a higher level of green finance. After winsorization, it is denoted as gf_w. The mediating variable is the logarithm of the number of green patents authorized (lnpatent), and the logarithm of the total number of green invention patents and utility model patents is used to measure the regional GTIL. Control variables include: The logarithm of per capita GDP (lnpergdp), the ratio of the added value of the secondary industry to GDP (industry), the urbanization rate (urban), the ratio of foreign investment to import and export (fdi), the ratio of local fiscal expenditure (fiscal), the ratio of thermal power generation (coal), the greening coverage rate (coverage), and the R&D economy are taken Ratio of fees to GDP (rd).

Table 1. Table of Variables

Variable category	Variable name	Variable symbol	Variable definition
Dependent variable	Carbon emission intensity	co2	Total carbon emissions per unit of GDP
Independent variable	Green finance index	gf	See above
Mediating variable	Number of green patent authorized after taking logarithm	lnpatent	Total number of green invention and utility model patents authorized and logarithmized
Control variable	Per capita GDP after taking logarithm	lnpergdp	Per capita GDP and logarithmized
	Proportion of secondary industry added value in GDP	industry	Proportion of secondary industry added value in GDP
	Urbanization rate	urban	Proportion of urban permanent residents to total population
	Ratio of foreign investment import and export	fdi	Proportion of foreign investment import and export to GDP
	Proportion of local fiscal expenditure	fiscal	Proportion of local fiscal expenditure in GDP
	Proportion of thermal power	coal	Proportion of thermal power

generation	generation in total power generation
Green coverage	Green coverage of built-up area
Proportion of R&D rd expenditure in GDP	Proportion of R&D expenditure in GDP

4.2 Data Source

This paper selects China's provincial administrative regions as samples, and the sample period is from 2006 to 2023. The original data of green finance index come from China Finance Yearbook and statistical yearbooks of various provinces and cities. Carbon emission data from the official website of EDGAR; green patent authorization data come from CNRDS; the control variables such as per capita GDP, industrial structure and urbanization rate are from the official website of national data. A small number of missing data were supplemented by linear interpolation.

4.3 Model Specification

4.3.1 Baseline Regression Model: To examine the direct impact of green finance on regional carbon emission intensity, the following panel baseline regression model is constructed:

$$co2_{it} = \alpha_0 + \alpha_1 gf_{it} + \sum \alpha_k Control_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

i represents the province and t represents the time.

4.3.2 Mediating effect model: To explore the transmission mechanism by which green finance influences regional low-carbon transformation, the number of green patent authorized after taking logarithm (lnpatent) is used as the mediating variable, and a stepwise regression-based mediating effect model is constructed. The specific form is as follows:

$$co2_{it} = \beta_0 + \beta_1 gf_{it} + \sum \beta_k Control_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

$$lnpatent_{it} = \gamma_0 + \gamma_1 gf_{it} + \sum \gamma_k Control_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

$$co2_{it} = \delta_0 + \delta_1 gf_{it} + \delta_2 lnpatent_{it} + \sum \delta_k Control_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

Model (1) examines the overall effect, model (2) examines the impact of green finance on the mediating variables, and model (3) examines the existence and type of the mediating effect.

5. Analysis of Empirical Results

5.1 Descriptive Statistical Analysis

This paper conducts descriptive statistical analysis on all core variables, presenting the number of observations, means, standard deviations, minimum values, and maximum values of both the original variables and the truncated variables. The results are shown in Tables 2 and 3.

Table 2. Descriptive Statistics of Variables (Original)

Variable	Obs	Mean	Std. dev.	Min	Max
gf	558	0.398	0.230	0.056	0.928
co2	558	1.845	1.380	0.113	10.154
gdpgrowth	558	0.087	0.036	-0.054	0.179
lnpergdp	558	1.436	0.646	-0.476	3.076
industry	558	0.406	0.084	0.146	0.613
urban	558	0.566	0.144	0.211	0.896
fdi	558	0.127	0.201	5.47e-06	1.044
fiscal	558	0.266	0.189	0.094	1.326
coal	558	0.717	0.259	0.001	1
coverage	558	38.744	4.694	18.1	49.8
rd	558	0.016	0.011	0.002	0.063

Table 3. Descriptive Statistical Results of Variables (after Winsorization)

Variable	Obs	Mean	Std. dev.	Min	Max
gf_w	558	0.398	0.230	0.067	0.873
co2_iw	558	1.833	1.327	0.145	6.657
gdpgrowth_w	558	0.087	0.035	0.006	0.161
lnpergdp_w	558	1.437	0.640	-0.013	2.940
industry_w	558	0.406	0.083	0.161	0.580
urban_w	558	0.566	0.144	0.227	0.893
fdi_w	558	0.127	0.199	0.000	0.972
fiscal_w	558	0.266	0.188	0.096	1.242
coal_w	558	0.718	0.258	0.029	0.998
coverage_w	558	38.756	4.606	24.4	48.5
rd_w	558	0.016	0.011	0.002	0.054

During the sample period, the mean value of green finance index is 0.398, the standard deviation is 0.230, the minimum value is 0.056, and the maximum value is 0.928. The mean value of carbon emission intensity is 1.845, the standard deviation is 1.379, the minimum value is 0.113, the maximum value is 10.154, and then it drops to 6.657 after winsorization, reflecting the extremely uneven level of low-carbon transition among regions. Control variables: the mean of the log of per capita GDP is 1.436, the standard deviation is 0.646; The mean value of the proportion of the secondary industry is 0.406, and the standard deviation is 0.084; The mean of urbanization rate is 0.566, with a range of 0.211-0.896; The mean value of thermal power ratio is 0.717, and the standard deviation is 0.258; The average value of

R&D expenditure is only 0.016, with a range of 0.0017-0.0629. There are 558 observations for each variable with no missing values, indicating good data quality.

5.2 Analysis of Benchmark Regression Results

In this paper, the panel benchmark regression model is constructed to estimate Model (1) which only includes the core explanatory variables and Model (2) which includes the core explanatory variables and all control variables respectively.

Table 4. Benchmark Regression Results

	(1)	(2)
	co2_w	co2_w
gf_w	-2.766*** (-12.60)	-0.681** (-2.91)
gdpgrowth_w		-1.889 (-0.97)
Lnpergdp_w		-0.968*** (-5.13)
Industry_w		4.659*** (6.97)
urban_w		1.791* (2.08)
fdi_w		-1.598*** (-5.86)
fiscal_w		1.710*** (5.86)
coal_w		1.902*** (9.75)
coverage_w		-0.0451** (-2.93)
rd_w		2.661 (0.43)
_cons	2.933*** (23.37)	0.844 (1.03)
N	558	558

t statistics in parentheses

* p<0.05, ** p<0.01, *** p<0.001

Table 4 shows that when only core explanatory variables are included, the coefficient of green finance index is -2.766 , which is significant at the level of 1%. After adding control variables, the coefficient is -0.681 , which is significant at the level of 1%. This shows that the development of green finance significantly reduces regional carbon emission intensity, and Hypothesis 1 is verified. Among the control variables, the logarithm of per capita GDP, the proportion of foreign investment in import and export, and the coefficient of green coverage are significantly negative; the coefficients of the proportion of the secondary industry, the urbanization rate, the proportion of local fiscal expenditure and the proportion of thermal power generation are significantly positive; the economic growth rate and the proportion of R&D expenditure are not significant.

5.3 Robustness Test

In this paper, we use two methods to replace the explained variable and increase the robust standard error of clustering to conduct robustness test. The robustness test results are shown in the robustness test table in Attached Table a.

After replacing the standardized carbon emission intensity, the coefficient of gf_w is -0.513 , which is significant at 1% level. After the clustering at the year level is added, the coefficient is -0.681 , which is consistent with the benchmark regression and the significance increases to 1%. The signs and significance of the control variables are basically consistent with the benchmark regression. The goodness of fit of the model is reasonable, indicating that the benchmark results are robust and not caused by errors in variable measurement methods or model setting.

5.4 Heterogeneity Analysis

This paper carries out heterogeneity analysis from the two dimensions of economic level grouping and time stage grouping (with 2015 as the boundary). Among them, 2015 is an important policy node for China's low-carbon transformation. The Paris Agreement was signed in 2015, and China has put forward clear carbon emission reduction targets, and various regions have begun to increase efforts in low-carbon development. According to the median of GDP per capita, the samples are divided into the high economic level group and the low economic level group. The results of heterogeneity analysis are shown in Table 5.

Table 5. Results of Heterogeneity Analysis

	(1)	(2)	(3)	(4)
	co2_w	co2_w	co2_w	co2_w
gf_w	-0.611*** (0.191)	-1.030** (0.510)	-0.982* (0.502)	-0.648*** (0.211)
gdpgrowth_w	-0.523 (1.223)	-4.813 (3.777)	-2.346 (3.441)	-0.486 (1.541)

lnpergdp_w	-0.838*** (0.157)	-1.191*** (0.351)	-0.994*** (0.312)	-1.303*** (0.271)
industry_w	4.624*** (0.535)	6.833*** (1.333)	4.803*** (1.068)	4.894*** (0.584)
urban_w	4.667*** (0.865)	1.190 (1.484)	0.694 (1.238)	5.594*** (1.119)
fdi_w	-1.887*** (0.239)	-0.855** (0.389)	-1.013*** (0.355)	-1.965*** (0.415)
fiscal_w	1.616*** (0.239)	2.040*** (0.441)	2.138*** (0.476)	1.821*** (0.270)
coal_w	1.590*** (0.194)	1.992*** (0.290)	2.261*** (0.307)	1.283*** (0.175)
coverage_w	0.008 (0.015)	-0.050* (0.025)	-0.051** (0.021)	0.017 (0.020)
rd_w	-19.077*** (5.272)	-23.488 (18.984)	3.298 (10.730)	-7.481 (6.770)
_cons	-2.840*** (0.939)	1.020 (1.191)	1.259 (1.131)	-3.035*** (1.114)
N	279	279	310	248
R ²	0.582	0.440	0.503	0.566
adj. R ²	0.566	0.419	0.487	0.548

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5 shows that according to the median GDP per capita, the coefficient of green finance index in the group with low economic level is -1.030 (5% significant), and the absolute value is higher than -0.611 (1% significant) in the group with high economic level, showing the feature of "increasing marginal effect." The reason lies in the weak foundation of green finance, high carbon emission intensity and large transformation space in regions with low economic level, and green finance can effectively make up for

the capital gap. In regions with high economic level, the level of green finance is relatively high, carbon emissions have been low, and the marginal inhibitory effect has been weakened. In terms of control variables, the coefficients of urbanization rate and R&D expenditure proportion in the group with high economic level are significantly negative, while those in the group with low economic level are insignificant. The coefficient of green coverage in the low economic level group is significantly negative. With 2015 as the boundary group, the coefficient of green finance index is significantly negative in both stages. The coefficient before 2015 is -0.982 (significant at 10%), and after 2015 it is -0.648 (significant at 1%). After the introduction of low-carbon policies in 2015, the promoting effect of green finance has become more stable and the efficiency of resource allocation has been improved. The absolute value of the coefficient decreases because the carbon emission intensity has been reduced in the later period, and the marginal inhibitory effect has been weakened. In terms of control variables, the coefficient of urbanization rate after 2015 is significantly positive and the absolute value is larger; Before 2015, the coefficient of green coverage was significantly negative, but not significant after 2015. After 2015, the absolute value of the proportion coefficient of thermal power generation is lower, indicating that the proportion of clean energy has increased; After 2015, the absolute value of the coefficient of the proportion of foreign investment in import and export is higher, indicating that the opening up pays more attention to low-carbon cooperation and the technology spillover effect is more significant.

5.5 Endogeneity Test

The model may suffer from endogeneity problems such as bidirectional causality, omitted variables and measurement error. This paper selects the one-period-lagged green finance index as the instrumental variable and adopts the two-stage least square regression method. The endogeneity test results are shown in the table of endogeneity test in Attached Table b. In the under-identification test, Anderson's typical correlation LM statistic is 472.906 and P value is 0.0000, rejecting the null hypothesis of under-identification. In the weak instrumental variable test, the Cragg-Donald Wald F statistic is 4510.993, which is much higher than the critical value of 16.38 for the maximum IV scale of 10%, and there is no weak instrumental variable problem. The number of instrumental variables is equal to the number of endogenous explanatory variables, and the model exactly identifies. The results of the second stage show that the coefficient of green finance index is -0.674 , which is significantly negative at the level of 1% and close to -0.681 of the benchmark regression, indicating that the promotion effect of green finance on low-carbon transformation is still established after solving the endogeneity. In the first stage, the one-period-lagged coefficient of the green finance index is 0.199, which is significantly positive at the level of 1%, and the R-squared is 0.972, indicating strong correlation of instrumental variables.

5.6 Mediating Effect Test

This paper takes the logarithm of the number of green patents granted ($\ln\text{patent}$) as the mediating variable, and uses the stepwise regression method to test the mediating effect, so as to verify whether green finance promotes regional low-carbon transformation by promoting green technology innovation. The test results of mediating effect are shown in Table 6.

Table 6. Mediating Effect Test Results

	(1)	(2)	(3)
	co2_w	lnpatent	co2_w
gf_w	-0.6814*** (0.2343)	0.9203*** (0.1530)	-0.2920 (0.2147)
gdpgrowth_w	-1.8892 (1.9510)	-11.6468*** (1.0320)	-6.8174*** (1.9814)
lnpergdp_w	-0.9680*** (0.1888)	2.1686*** (0.1201)	-0.0504 (0.2245)
industry_w	4.6588*** (0.6683)	2.8766*** (0.4709)	5.8760*** (0.6526)
urban_w	1.7908** (0.8615)	-5.2530*** (0.5573)	-0.4320 (0.8518)
fdi_w	-1.5975*** (0.2726)	-0.0864 (0.1888)	-1.6341*** (0.2597)
fiscal_w	1.7097*** (0.2919)	-4.5042*** (0.2697)	-0.1962 (0.4116)
coal_w	1.9018*** (0.1950)	-0.6338*** (0.1346)	1.6336*** (0.1830)
coverage_w	-0.0451*** (0.0154)	0.0068 (0.0097)	-0.0422*** (0.0153)
rd_w	2.6608 (6.1866)	42.0126*** (4.2776)	20.4378*** (6.1389)
lnpatent			-0.4231*** (0.0756)

_cons	0.8442 (0.8180)	6.9251*** (0.5648)	3.7744*** (0.9073)
<i>N</i>	558	558	558
<i>R</i> ²	0.565	0.894	0.603
adj. <i>R</i> ²	0.557	0.892	0.595

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6 shows that in the first-step benchmark regression, the coefficient of green finance index is -0.6814 , which is significant at the level of 1%, and the total effect is significantly negative. In the second step, the coefficient of green finance index on the number of green patents authorized after taking logarithm is 0.9203 , which is significant at the level of 1%, indicating that green finance significantly promotes green technological innovation. In the third step, after both green finance and the number of green patents authorized after taking logarithm are included, the coefficient of the number of green patents authorized after taking logarithm is -0.4231 , which is significant at the level of 1%, indicating that GTE significantly reduces carbon emission intensity. The coefficient of green finance index decreases from -0.6814 to -0.2920 and is no longer significant. This shows that the direct impact of green finance on carbon emission intensity disappears, and all its promoting effect is realized through green technology innovation, and green innovation plays a complete intermediary role, which verifies Hypothesis 2.

6. Conclusions and Policy Recommendations

6.1 Research Findings

Based on provincial panel data from 2006 to 2023, this study constructs a green finance development index and employs panel fixed effects model, mediation effect model, and instrumental variable method to examine the impact of green finance on regional low-carbon transformation and the transmission mechanism. The main findings are as follows: First, green finance significantly promotes regional low-carbon transformation. The green finance index is significantly negatively correlated with carbon emission intensity, and this conclusion remains robust even after replacing the dependent variable, using clustering robust standard errors, and controlling endogeneity through instrumental variable method. Second, the impact of green finance exhibits significant heterogeneity. The promoting effect is stronger in low-income regions, showing a "marginal effect increasing" pattern; after the signing of the 2015 Paris Agreement, the promoting effect of green finance becomes more stable, and the policy guidance effect strengthens. Third, green technological innovation is the core transmission mechanism. Green finance significantly promotes the increase in green patent authorizations, and the increase in green patent authorizations significantly reduces carbon emission intensity; after including the mediating variable, the

direct effect of green finance is no longer significant, and green technological innovation plays a complete mediating role.

6.2 Policy Recommendations

First, we need to improve the green finance policy system and strengthen support for low-carbon transformation. We will improve the green finance standard system, clarify the identification standards for green projects, and prevent "greenwashing"; enrich green credit, green bonds, green insurance, green funds, carbon finance and other products; and strengthen incentives such as discount interest, guarantee and tax preference, reduce the cost of green financing, guide social capital to invest in low-carbon fields, strengthen green financing support for small and medium-sized enterprises and non-state-owned enterprises, and avoid possible problems of "scale discrimination" and "ownership discrimination" (Wang, 2023).

Second, we need to focus on green technology innovation and open up transmission channels. Set up a special fund for green technology innovation to support R&D and industrialization; optimize the green patent examination and protection mechanism, shorten the examination period, strengthen intellectual property protection; and build a platform for green technology transformation and promote collaborative innovation between industries, universities and research institutes.

Third, we need to implement differentiated green finance policies to improve precision. Regions with low economic level should increase policy preference, expand the coverage of green finance, and give priority to green infrastructure construction and green industry cultivation. Regions with high economic levels should focus on improving quality and efficiency, guide the allocation of financial resources to high-end fields such as green and low-carbon technology R&D and green service industry, and promote the quality improvement of low-carbon transformation.

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Appendix

Attached Table a Robustness test table

	(1)	(2)
	co2_z	co2_w
gf_w	-0.513*** (0.174)	-0.681*** (0.083)
gdpgrowth_w	-1.503 (1.444)	-1.889* (0.978)
lnpergdp_w	-0.742*** (0.147)	-0.968*** (0.167)
industry_w	3.429*** (0.496)	4.659*** (0.270)
urban_w	1.437** (0.649)	1.791* (0.894)
fdi_w	-1.192*** (0.203)	-1.598*** (0.214)
fiscal_w	1.256*** (0.216)	1.710*** (0.168)
coal_w	1.412*** (0.146)	1.902*** (0.118)
coverage_w	-0.034*** (0.012)	-0.045*** (0.014)
rd_w	2.091 (4.549)	2.661 (2.477)
_cons	-0.699 (0.599)	0.844 (0.884)

N	558	558
R^2	0.552	0.565
adj. R^2	0.544	0.557

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Attached Table b Table of endogeneity test

	(1)	(2)
	gf_w	co2_w
gf_lag	0.199*** (0.045)	
gdpgrowth_w	0.405*** (0.148)	-1.731 (1.594)
lnpergdp_w	-0.015 (0.032)	-0.948*** (0.174)
industry_w	-0.214*** (0.078)	4.877*** (0.575)
urban_w	-0.426*** (0.125)	2.221*** (0.813)
fdi_w	0.023 (0.036)	-1.740*** (0.288)
fiscal_w	-0.101* (0.061)	1.812*** (0.307)
coal_w	0.056 (0.036)	1.894*** (0.192)
coverage_w	-0.003*** (0.001)	-0.038*** (0.013)

rd_w	3.653*** (0.922)	0.497 (6.049)
2007.year	0.000 (.)	
2008.year	0.036*** (0.013)	
2009.year	0.058*** (0.015)	
2010.year	0.070*** (0.018)	
2011.year	0.082*** (0.022)	
2012.year	0.100*** (0.026)	
2013.year	0.114*** (0.029)	
2014.year	0.149*** (0.033)	
2015.year	0.167*** (0.036)	
2016.year	0.170*** (0.039)	
2017.year	0.197*** (0.041)	

2018.year	0.219*** (0.044)
2019.year	0.223*** (0.047)
2020.year	0.255*** (0.051)
2021.year	0.244*** (0.050)
2022.year	0.282*** (0.055)
2023.year	0.269*** (0.055)
110000.province	0.000 (.)
120000.province	-0.238*** (0.038)
130000.province	-0.077 (0.057)
140000.province	-0.204*** (0.061)
150000.province	-0.400*** (0.056)
210000.province	-0.024 (0.048)

220000.province	-0.241*** (0.056)
230000.province	-0.046 (0.057)
310000.province	0.084*** (0.031)
320000.province	0.063 (0.042)
330000.province	0.073* (0.043)
340000.province	-0.291*** (0.057)
350000.province	-0.039 (0.049)
360000.province	-0.218*** (0.059)
370000.province	-0.101** (0.048)
410000.province	-0.272*** (0.062)
420000.province	-0.057 (0.053)
430000.province	-0.086 (0.056)

440000.province	0.060 (0.044)
450000.province	-0.101 (0.063)
460000.province	-0.072 (0.054)
500000.province	-0.051 (0.050)
510000.province	-0.257*** (0.063)
520000.province	-0.480*** (0.070)
530000.province	-0.451*** (0.071)
540000.province	-0.429*** (0.094)
610000.province	-0.467*** (0.058)
620000.province	-0.479*** (0.071)
630000.province	-0.388*** (0.071)
640000.province	-0.405*** (0.061)

650000.province	-0.425*** (0.064)	
gf_w		-0.674*** (0.242)
_cons	0.736*** (0.111)	0.202 (0.712)

<i>N</i>	527	527
<i>R</i> ²	0.972	0.558
adj. <i>R</i> ²	0.969	0.549

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$