



The path of green finance to promote the realization of low-carbon economic transformation under the carbon peaking and carbon neutrality goals: Theoretical model and empirical analysis

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ARTICLE INFO

Keywords:

Green finance
Low-carbon economic transformation
Green Solow model
Upgrading of industrial structure
Technological innovation

ABSTRACT

In 2020, China proposed the Carbon Peaking and Carbon Neutrality Goals, promoting low-carbon economy and the related green financial market environment. The introduction of relevant policies means that China's green financial service system is undergoing transformation. This is not only a manifestation of China's active commitment to environmental protection obligations, but also a major responsibility for China to actively respond to global climate change. It also directly puts forward higher requirements for China to accelerate the implementation of low-carbon economic transformation. Based on the panel data of 30 provinces (cities) from 2006 to 2020, this article realistically uses panel data information as the most fundamental basis, and adopts the Mediating Effect and GMM model to empirically analyze and verify the implementation path of green finance to assist in the low-carbon transformation of the economy. The study found that green finance could assist in the low-carbon transformation of the economy: there are paths of green finance → upgrading industrial structure → GDP carbon emission intensity and green finance → technological innovation → GDP carbon emission intensity. Heterogeneity analysis showed that, in high-carbon emission areas, the upgrading of industrial structure has played a negative mediating effect in the process of green finance assisting in the low-carbon transformation of the economy. In addition, both the technological innovation paths in high-carbon emission areas and the upgrading industrial structure and technological innovation path in low-carbon emission areas have played a positive mediating effect in the process of green finance assisting in the low-carbon transformation of the economy. The research in this article enriches and develops the theory of finance and economic growth, providing a reference basis for achieving the Carbon Peaking and Carbon Neutrality Goals and coping with the difficulties encountered in the low-carbon transformation of the economy. It is of positive significance in the field of low-carbon development.

1. Introduction

The time and the environment are constantly developing. With the rapid development of China's economy since the reform and opening-up, China's economy has maintained high-speed growth for >40 years and achieved remarkable achievements. At the same time, we have to admit that China's extensive economic growth model of high-energy consumption and high pollution has caused serious ecological and environmental problems, which is contrary to the green development principle under the Carbon Peaking and Carbon Neutrality Goals. It is obvious that the contradiction between economic growth and

environmental protection is increasing.

In 2011, the "Work Plan for Controlling Greenhouse Gas Emissions during the 12th Five-Year Plan" issued by the State Council clearly proposed the green and low-carbon development goals during the "12th Five-Year Plan" period (2011–2015). In 2016, the "13th Five-Year Plan" outlined the "Five Development Concepts" of innovation, coordination, green, openness, and sharing. In 2020, President Xi said at the 75th United Nations General Assembly that China would adopt more effective policies and measures to strive to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. The various policies adopted by China have shown its determination to vigorously promote

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<https://doi.org/10.1016/j.irfa.2024.103227>

Received 30 November 2023; Received in revised form 15 February 2024; Accepted 16 March 2024

Available online 20 March 2024

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green and low-carbon development. Green finance can provide targeted financial services in terms of investment and financing, operation, and risk management for clean energy and other environmental improvement projects based on national environmental protection policies, guiding the transformation and upgrading of the economy towards a low-carbon development direction.

The foreign and local scholars have also confirmed that green finance is an important guarantee for achieving sustainable economic development and coordinating human and nature (Nam, 2017; Pastor, Stambaugh, & Taylor, 2022; Hunjra, Hassan, Zaied, & Managi, 2023; Wu & Chiu, 2023). On the one hand, green finance provides new financing measures for green enterprises and rationally adjusts the proportion of various credit assets and reduces cost of various financing, and raises sufficient development funds for the green industry (De Angelis, Tankov, & Zerbib, 2022; Qian & Yu, 2024), which can explore the development potential of China's green environmental protection enterprises and optimize the layout of China's existing industrial structure (Bai, Qi, Li, & Xu, 2023; Sheng & Liu, 2023). On the other hand, the in-depth development of green finance has a significant role in promoting technological innovation (Li, Liao, Wang, & Huang, 2018; Markandya et al., 2015; Wang, Nie, Peng, & Li, 2017). In this process, green finance has become a link of communication and mutual benefit between the financial industry and the environmental protection industry, effectively alleviating the resource problem faced by China's environmental protection industry, empowering high-quality economic growth, and facilitating low-carbon economic transformation (Gianfrate & Peri, 2019).

In recent years, China's green finance has been developing continuously. As of the end of the third quarter of 2023, China's green loan balance was 28.58 trillion yuan, up 36.8% year-on-year, ranking first in the world. During the same period, the domestic green bond market balance was 1.98 trillion yuan, ranking second in the world. In 2022, China's property insurance companies' agricultural insurance premiums were 121.935 billion yuan, up 24.95% year-on-year; industrial pollution control investment was 28.571 billion yuan, down 14.77% year-on-year; government energy conservation and environmental protection fiscal expenditure was 541.28 billion yuan, accounting for 2.08% of general public budget expenditure, down 0.17% year-on-year. The strategic position of green finance in China's high-quality development stage has steadily increased, and it is an indispensable force for achieving low-carbon economic transformation (Barnett, Brock, & Hansen, 2020; Li, Hu, & Hong, 2024; Sun, Guan, Cao, & Bao, 2022). Therefore, it is an inevitable requirement to deeply analyze the relationship between green finance and low-carbon economic transformation to adapt to the social background. More recent empirical studies tend to believe that green finance plays a positive role in curbing heavy pollution enterprises and improving the ecological environment (Liu, Wang, Zhang, & Zhang, 2018). Some studies have also explored the relationship between financial development and carbon emissions, but these documents use traditional financial development indicators and lack systematic demonstration and theoretical analysis of the relationship between green finance and low-carbon economic transformation (Abbasi & Riaz, 2016; Liu & Song, 2020). In view of this, this article systematically analyzes the implementation path of green finance to assist in the low-carbon transformation of the economy from both theoretical and empirical perspectives. The possible innovations of this article are as follows: (1) this article introduces green finance factors into the green Solow model constructed by Brock and Taylor (2010) for model expansion, deriving that green finance can assist in the low-carbon transformation of the economy, systematically building the relationship between green finance and low-carbon economic transformation, and providing an improved theoretical analysis framework for analyzing the role of green finance in assisting in the low-carbon transformation of the economy. (2) This article comprehensively studies the implementation path of green finance in promoting low-carbon economic transformation from both theoretical and empirical perspectives. On the one hand, it can enrich the theory of green financial development and

economic growth. On the other hand, it can reveal the inherent logic of the low-carbon transition of the economies in different areas, providing research enlightenment for achieving the "dual carbon" goal.

2. Theoretical analysis and research hypothesis

Brock and Taylor (2010) constructed the Green Solow Model based on the traditional Solow Model to verify the inverted "U" relationship of the Environmental Kuznets Curve. This model considers the realistic data characteristics of the continuous decline in carbon emission reduction costs and pollution emission intensity. Therefore, based on the Green Solow Model constructed by Brock and Taylor (2010), this article innovatively adds green finance factors to expand the model. The main assumptions of the model are that pollution emissions are by-products of the production process (i.e., pollution is treated as an undesirable output), and that all green finance are invested in environmental governance. Non-renewable energy is a capital loss due to its non-renewability. In addition, the model inherits a series of assumptions of the traditional Solow growth model, such as the production function satisfying the Inada Conditions and the savings rate being exogenous. The main assumptions of the expanded green Solow model are as follows:

$$Y = F(K, BL) \quad (1)$$

$$\dot{K} = I - \delta K - G - R \quad (2)$$

$$G = \nu_G K \quad (3)$$

$$R = \nu_R K \quad (4)$$

$$\dot{L} = nL \quad (5)$$

$$\dot{B} = g_B B \quad (6)$$

$$I = sY \quad (7)$$

$$E = \Omega aY \quad (8)$$

$$\dot{\Omega} = -g_A \Omega \quad (9)$$

$$\dot{a} = (g_R - g_G)a \quad (10)$$

In the formula, Y is the total output level. K , B , and L are the "green" capital stock considering environmental governance, labor effectiveness, and labor quantity, respectively. G is the amount of investment in green finance to govern environmental pollution, and ν_G is the proportion of the amount of investment in green finance to govern environmental pollution in the total capital. R is non-renewable energy, and ν_R is the proportion of the consumption of non-renewable energy in the total capital. I is the total investment. s and δ are the savings rate and depreciation rate, respectively. $\dot{K}$, $\dot{B}$ and $\dot{L}$ are the rates of change of the "green" capital stock, labor effectiveness, and labor quantity over time. g_B is the growth rate of labor effectiveness (i.e., the level of technology used for production). n is the exogenous population growth rate. E is the total amount of pollution emissions. Ω represents the level of environmental protection technology (the decline rate of pollution emission intensity), and it is assumed that the technological progress rate is g_A . The a is an intensity function, which reflects how the non-renewable energy (R) and green finance (G) input into production affect pollution emission intensity. Therefore, the change rate of emission intensity is related to g_R and g_G , and the emission intensity will not decrease in the absence of any emission reduction input. Therefore, $a(0) = 1$. Brock and Taylor (2010) assume that a is a concave function, so $a' < 0$ and $a'' > 0$. In addition, as in the traditional Solow model, capital in capitalization is represented by capital in capitalization.

To facilitate the solution, it is assumed that the production function is of Cobb-Douglas form and the returns to scale are constant. Further organizing the main variables (Y , K , E) of the model into the form of unit labor, the important equations for the three key variables are as follows:

$$y = k^\alpha \quad (11)$$

$$\dot{k} = sy - (n + \delta + \nu_G + \nu_R + g_B)k \quad (12)$$

$$e = \Omega ay \quad (13)$$

In the equation, the parameter α is the capital output elasticity in the production function, and $\dot{k}$ is the rate of change in the stock of unit effective labor capital over time. Consistent with the traditional Solow model, all lowercase letters are the level of unit labor (i.e., $y = Y/BL$, $k = K/BL$, $e = E/BL$). By converting the main variables to the level of unit labor, the model is dimensionally reduced, making the solution more concise. Further calculating its growth rate, the equations are expressed as follows:

$$g_k = \frac{\dot{k}}{k} = s k^{\alpha-1} - (n + \delta + \nu_G + \nu_R + g_B) \quad (14)$$

$$g_e = \frac{\dot{e}}{e} = \alpha g_k + g_R - g_A - g_G \quad (15)$$

Because e is the carbon emission level per unit of effective labor, the relationship between e and the total carbon emission E is as follows:

$$E = \frac{E}{BL} BL = e \cdot BL \quad (16)$$

According to formula (16), the growth rate of total carbon emissions can be obtained:

$$g_E = \frac{\dot{E}}{E} = \alpha g_k + n + g_B + g_R - (g_A + g_G) \quad (17)$$

When the initial state of the economy's unit effective labor capital stock $k(0)$ is determined, the dynamic paths of variables k and E are completely determined by the above equations. At the steady state, the growth rates of per capital stock, per capital output, and per capital consumption are all g_B , while the growth rates of total capital stock, total output, and total consumption are all $n + g_B$. Since the unit effective labor capital stock does not change over time at the steady state, that is $g_k = 0$, according to eq. (17), the growth rate of total emissions at the steady state is $g_E = n + g_B + g_R - (g_A + g_G)$. In order to achieve sustainable growth, the pollutant emissions cannot grow indefinitely at the steady state, so it is required that $g_E < 0$, that is $n + g_B + g_R < (g_A + g_G)$.

As the growth rate of the stock of labor capital per unit decreases with the increase in the stock of capital k , the growth rate of total emissions g_E also decreases with the growth of k . Therefore, if the conditions for sustainable growth $n + g_B + g_R < (g_A + g_G)$ are met, there will be a certain time T before reaching a steady state, when the growth rate of total pollution emissions drops to 0 while the growth rate of the stock of effective labor capital per unit remains positive (because the economy has not yet reached a steady state). At this point, the total pollution emissions reach a peak at the time point T . After time point T , capital continues to accumulate, the growth rate of the stock of capital continues to decline, and the growth rate of total emissions will be < 0 , and the overall environmental quality begins to improve. Eventually, the economy reaches a steady state, and the growth rate of the stock of labor capital per unit k drops to 0. The total pollution emissions decrease at a constant rate $g_E = n + g_B + g_R - (g_A + g_G)$ (notes that this value is negative), and the environmental quality continues to improve. In this case, we can observe the process of pollution emissions first increasing with economic growth, reaching a peak at time point T , and then gradually decreasing, which is the inverted "U" shaped EKC curve, as shown in Fig. 1. Note that T^* in the figure is the time when the economy

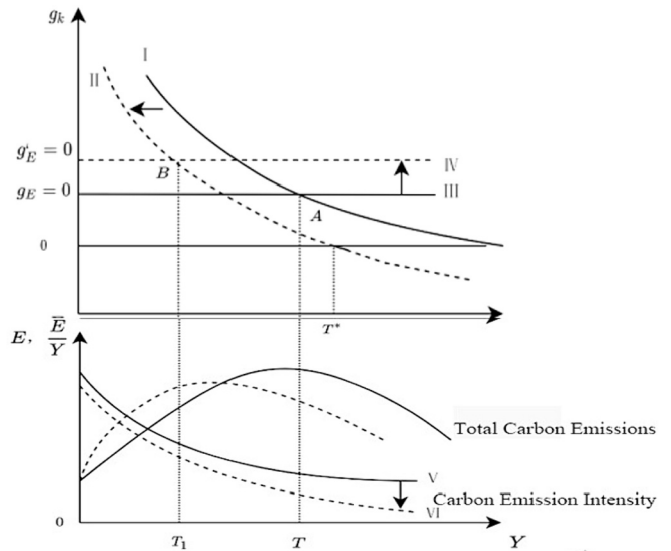


Fig. 1. Environmental Kuznets Curve Based on the Green Solow Model. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

reaches a steady state. According to formula (8), the pollution emission intensity is $\frac{E}{Y} = \Omega a$, where Ω decreases at a rate of g_A , and the rate of a also continues to decrease at the rate of $(g_R - g_G)$ due to the development of green finance, so the pollution emission intensity always decreases.

As we can see from Fig. 1, when green finance is not considered, the growth rate of the unit labor capital stock $g_k = s k^{\alpha-1} - (n + \delta + \nu_R + g_B)$ corresponds to the curve I. If the growth rate of total carbon emissions is equal to zero ($g_E = 0$, total carbon emissions reach a peak), the corresponding g_k can be expressed as: $g_k = \frac{g_A - (n + g_B + g_R)}{\alpha}$ corresponding to the straight line III in Fig. 1, intersecting with curve I at point A. When green finance is considered, the growth rate of the unit effective labor "green" capital stock $g_k = s k^{\alpha-1} - (n + \delta + \nu_G + \nu_R + g_B)$ corresponds to the curve II in Fig. 1. If the growth rate of total carbon emissions is equal to zero ($g'_E = 0$, total carbon emissions reach a peak), the corresponding g_k can be expressed as: $g_k = \frac{g_A + g_G - (n + g_B + g_R)}{\alpha}$ corresponding to the straight line IV in Fig. 1, intersecting with curve II at point B. Therefore, green finance moves the curve from I to II, and the curve from III to IV, corresponding to the carbon emission intensity curve moving from V to VI. That is to say, green finance reduces carbon emission intensity and can contribute to a low-carbon transition of the economy. Based on the above analysis, this paper proposes the following hypothesis:

H1: Under the Carbon Peaking and Carbon Neutrality Goals, green finance can help the low-carbon transformation of the economy.

2.1. Transmission path based on industrial structure

Non-renewable energy (coal, oil, natural gas, etc.) is the main source of carbon emissions. These energy sources have typical characteristics, which is that the difficulty factor of resource recycling is very high. In view of this, the biggest advantage of green finance is to gradually phase out high-energy-consuming industries through intentional support for green industries, achieve green finance, achieve sustainable development goals, and ultimately promote industrial structure upgrading and help the vision of low-carbon economic transformation goals. First, green finance can provide long-term financial supply for the development of high-tech industries, thus promoting industrial structure upgrading. The most critical point is that industrial structure upgrading can directly control the increase of costs and achieve low energy con-

sumption. Secondly, green finance has green attributes and is essentially a sustainable development strategy. Therefore, it is more inclined to green and clean industries, as these industries are sunrise industries with good development prospects and deserve a lot of financial capital investment to promote their evolution. Green finance reduces the capital cost of low-pollution and low-energy-consumption industries through differential pricing, ultimately achieving green sustainable development and effectively guiding market investment orientation to promote industrial structure upgrading. Thirdly, green finance can remove geographical and industry restrictions, integrate advantages, gather raw material markets, technical talent markets, product sales markets, etc., related to the industry together, improve the utilization efficiency of raw materials, accelerate the process of industrial structure adjustment, and promote the optimization and upgrading of industrial structure. Fourth, green finance itself belongs to the field of information technology. With its information advantages, it has formed unique industry risk identification and the evaluation mechanism in the objective fact of the existence of information gaps, effectively avoiding many shortcomings in the mechanism. It can accurately assess and price the various risks faced by emerging industries, and design diversified green financial products and services to decentralize industry risks and promote industrial structure upgrading. Industrial structure and low-carbon economic transformation directly ensure low energy consumption, which is an important prerequisite for scientific development. Industrial structure upgrading is the transformation from a low value-added, labor-intensive industrial structure dominated by labor-intensive industries to a high value-added, technology-intensive industrial structure dominated by technology-intensive industries. According to the theory of industrial structure, we can infer that industrial structure upgrading will ultimately achieve low-carbonization of high-carbon sectors, expand low-carbon sectors, increase the proportion of clean energy in the energy structure, and reduce the consumption of non-renewable energy (R). The specific model is reflected in the reduced g_R in the extended green Solow model constructed in this article. At the same time, the reduction in g_R also means that the proportion of non-renewable energy consumption in total capital ν_R decreases. Through industrial structure upgrading, the impact of green finance on carbon emission intensity is shown in Fig. 2.

As can be seen from Fig. 2, in the green Solow model incorporating green finance and carbon emission intensity, when the consumption of non-renewable energy (g_R) is not reduced, the growth rate of the unit

effective labor “green” capital stock $g_k = sk^{\alpha-1} - (n + \delta + \nu_G + \nu_R + g_B)$ corresponds to curve I in Fig. 2. If the growth rate of total carbon emissions equals zero ($g_E = 0$, total carbon emissions reach a peak), the corresponding g_k can be expressed as: $g_k = \frac{g_A + g_G - (n + g_B + g_R)}{\alpha}$ corresponding to the straight line III in Fig. 2, intersecting with curve I at point A. When the consumption of non-renewable energy (g_R) is reduced, the growth rate of the unit effective labor “green” capital stock $g_k = sk^{\alpha-1} - (n + \delta + \nu_G + \nu'_R + g_B)$ corresponds to curve II in Fig. 2. If the growth rate of total carbon emissions equals zero ($g'_E = 0$, total carbon emissions reach a peak), the corresponding g_k can be expressed as: $g_k = \frac{g_A + g_G - (n + g_B + g'_R)}{\alpha}$ corresponding to the straight line IV in Fig. 2, intersecting with curve II at point B. Since the growth rate of total carbon emissions $g_E = \alpha g_k + n + g_B + g_R - (g_A + g_G)$ according to formula (17), reducing the consumption of non-renewable energy (g_R) means that the same economic output is accompanied by less carbon emissions. Therefore, green finance promotes the curve to move from curve I to curve II, curve III to curve IV, and the corresponding carbon emission intensity curve to move from curve V to curve VI through the path of industrial structure upgrading, which helps the economy to transition to low carbon. Based on the above analysis, this paper proposes the following hypotheses:

H2: Under the Carbon Peaking and Carbon Neutrality Goals, green finance can assist the low-carbon transformation of the economy through the path of upgrading of industrial structure.

2.2. Conduction path based on technological innovation

Innovation is the source of technological progress, and the science and technology are the prerequisites for sustainable development, especially in the low-carbon field, where it will be of necessary to create new low-carbon technologies through technological innovation. Green finance achieves the ultimate goal of economic low-carbon transformation by encouraging technological innovation. Firstly, green finance and technological innovation should be coordinated and complementary. The technological innovation often requires huge financial support, but due to unstable returns and high risks, green finance under the dual-carbon goal is difficult to obtain the favor of traditional capital. We must realize that green finance can provide rich financing channels for the green innovation projects and meet their financial needs. Secondly, the financial institutions that rely on green finance have information collection capabilities, and can establish a green rating and certification mechanism for enterprises, reducing information asymmetry in the financial market and enabling investors to better participate in technological innovation based on real and effective information. Thirdly, green finance provides corresponding financial investment portfolios based on the differentiated characteristics of different factors such as cost, duration, and liquidity, which can balance the risk-return level of the overall investment portfolio of innovative products, reduce the liquidity risk of innovative projects, and make it possible to improve the level of technological innovation. Fourthly, green finance can supervise whether the funds of enterprises flow to the most promising and valuable technological innovation activities by virtue of its information advantage, increase the default cost of enterprises, and provide a good market environment for R&D activities to ensure the smooth development of R&D and innovation activities. Technological innovation is the core driving force for promoting economic low-carbon transformation. On the one hand, technological innovation can effectively exert the competitive effect, accelerate the breakthrough of renewable energy storage and application technology, promote the rapid upgrading of energy products and functions, achieve the improvement and optimization of carbon emission reduction efficiency, and promote the low-carbon transformation of the economy. On the other hand, technological innovation plays a knowledge spillover effect, which can help China from a technology follower to a leader,

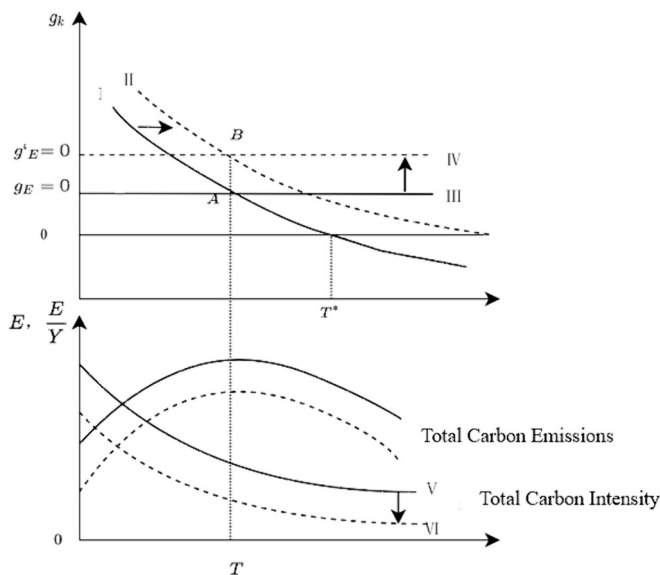


Fig. 2. Environmental Kuznets Curve under the path of industrial structure upgrading.

achieve the transformation in the field of information technology, and ultimately break through the technological blockade of developed countries. Through independent innovation, we can master core and key technologies, avoid the risk of technological suppression, and promote the low-carbon transformation of the economy. This is reflected in the increase of g_A in the extended green Solow model constructed in this article. Through technological innovation, the impact of green finance on carbon emission intensity is shown in Fig. 3.

As can be seen from Fig. 3, in the green Solow model that includes green finance and carbon emission intensity, when the level of technological innovation (g_A) has not been improved, the growth rate of total carbon emissions is equal to zero ($g_E = 0$, total carbon emissions reach a peak), corresponding to g_k , which can be expressed as: $g_k = \frac{g_A + g_G - (n + g_B + g_R)}{\alpha}$ corresponding to the straight line I in Fig. 3, intersecting with the g_k curve at point A. When the level of technological innovation (g_A) is improved, the growth rate of total carbon emissions is equal to zero ($g'_E = 0$, total carbon emissions reach a peak), corresponding to g'_k , which can be expressed as: $g'_k = \frac{g'_A + g_G - (n + g_B + g_R)}{\alpha}$ corresponding to the straight line II in Fig. 3, intersecting with the g_k curve at point B. Because there is no impact on the growth rate of the “green” capital stock per unit of effective labor $g_k = sk^{\alpha-1} - (n + \delta + \nu_G + \nu_R + g_B)$ regardless of whether the level of technological innovation (g_A) is improved, green finance enables the curve to move from I to II through technological innovation, corresponding to the carbon emission intensity curve moving from V to VI, and facilitates the low-carbon transformation of the economy. Based on the above analysis, this paper proposes the following hypotheses:

H3: Under the Carbon Peaking and Carbon Neutrality Goals, green finance helps the low-carbon transformation of the economy through technological innovation.

3. Research design

3.1. Empirical model

The research objective of this article is to analyze the path of green finance to facilitate the low-carbon transformation of the economy. In the estimation of the model, due to the inertia of economic growth, the economic growth in the previous period will have an impact on the

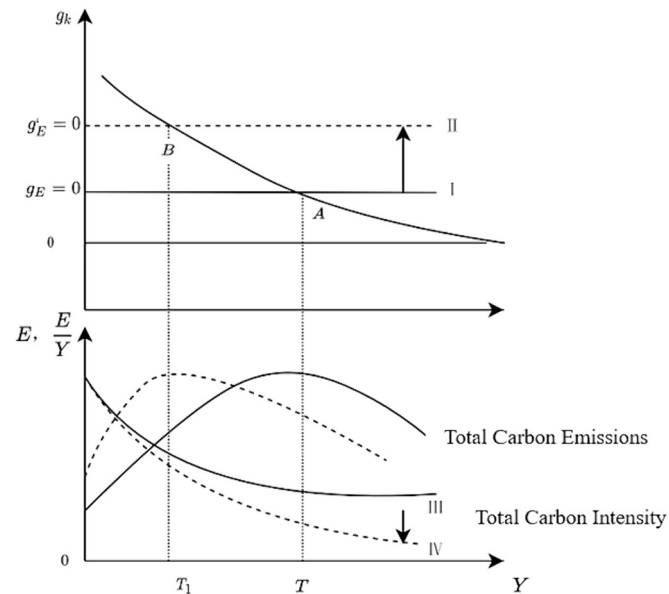


Fig. 3. Environmental Kuznets Curve under the path of technological innovation.

current economic growth. Obviously, there will be explained variables that are correlated with the error terms, and direct OLS estimation is biased and inconsistent. Generalized method of moments (GMM) allows for heteroskedasticity and serial correlation in the error terms, and can solve the endogenous problem in the model by using the lagged terms of the variables as instrumental variables. At the same time, the system GMM model adds the first-order difference lagged terms of the dependent variable as instrumental variables in the horizontal equation, which has a smaller bias than the difference GMM estimation. Therefore, based on Arellano and Bond (1991) and Blundell and Bond (1998), this article adopts System GMM. The benchmark model of this article is constructed as follows:

$$CG_{it} = \alpha_1 + \beta_{11}CG_{i,t-1} + \beta_{12}GF_{it} + \beta_{13}Z_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (18)$$

Where, the CG_{it} represents the GDP carbon emission intensity, $CG_{i,t-1}$ represents the first lag term of the GDP carbon emission intensity, GF_{it} represents green finance, Z_{it} represents the set of other control variables that may affect the explained variables. η_i represents the individual effect, μ_t represents the time effect, and ε_{it} is the residual term.

This article refers to the mediating effect test procedure proposed by Gonzalez and MacKinnon (2021) to test the mediating effect of industrial structure upgrading and technological innovation. The testing principle of mediating effect is shown in Fig. 4. c is the total influence coefficient of X on Y , a is the influence coefficient of X on M , and b is the influence coefficient of M on Y . Then, the mediating effect of the mediating variable M is $\frac{ab}{c} = \frac{ab}{ab+c}$.

Adding formula (19) and formula (20) to formula (18) to construct a mediating effect model of industrial structure upgrading:

$$IS_{it} = \alpha_2 + \beta_{21}IS_{i,t-1} + \beta_{22}GF_{it} + \beta_{23}Z_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (19)$$

$$CG_{it} = \alpha_3 + \beta_{31}CG_{i,t-1} + \beta_{32}GF_{it} + \beta_{33}IS_{it} + \beta_{34}Z_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (20)$$

Adding formula (21) and formula (22) to formula (18) to construct a mediating effect model of technological innovation:

$$ZL_{it} = \alpha_4 + \beta_{41}ZL_{i,t-1} + \beta_{42}GF_{it} + \beta_{43}Z_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (21)$$

$$CG_{it} = \alpha_5 + \beta_{51}CG_{i,t-1} + \beta_{52}GF_{it} + \beta_{53}ZL_{it} + \beta_{54}Z_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (22)$$

Where, the subscript i is the province identification, t is the year identification, $i = 1, 2, \dots, 30$; $t = 1, 2, \dots, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$, and α_6 are constant terms, $\beta_{11}, \beta_{12}, \beta_{13}, \beta_{21}, \beta_{22}, \beta_{23}, \beta_{31}, \beta_{32}, \beta_{33}, \beta_{34}, \beta_{41}, \beta_{42}, \beta_{43}, \beta_{51}, \beta_{52}$ and β_{53} are the estimated coefficients. IS_{it} represents the upgrading of industrial structure, $IS_{i,t-1}$ represents the first lag term of the upgrading industrial structure, ZL_{it} represents the patent authorization situation, $ZL_{i,t-1}$ represents the first lag term of the patent authorization. Other variables are same as previously mentioned.

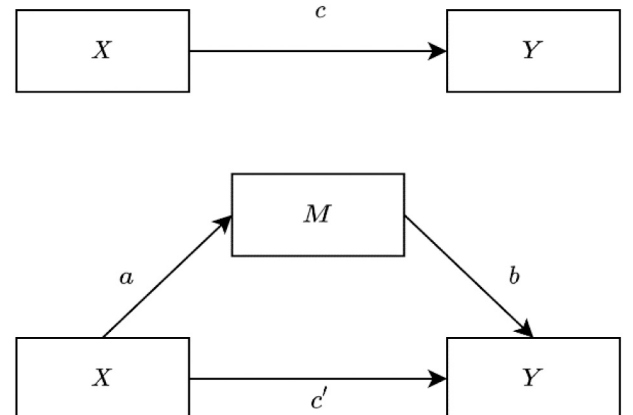


Fig. 4. The testing principle of mediating effect.

3.2. Variable selection and data sources

3.2.1. The explained variable

The intensity of carbon emissions in GDP directly determines the risk of variable impact. Economic low-carbon transformation is to achieve the control and reduction of carbon dioxide emissions under the premise of ensuring sustainable economic growth, which is manifested as the reduction of the intensity of carbon emissions in GDP (Wang, Chen, Wu, & Nie, 2019). Therefore, this article This article draws on the approach of Sheng and Liu (2023) to chooses the intensity of carbon emissions in GDP to measure the economic low-carbon transformation. The calculation steps of the intensity of carbon emissions in GDP are as follows:

Firstly, determine the carbon dioxide emissions of energy sources. The greenhouse gas emissions are usually calculated based on the consumption of fossil fuels. According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the carbon dioxide emissions are estimated based on the quantity of fossil fuels and the corresponding default emission factors, and the final carbon dioxide emissions of various energy sources are calculated as follows:

$$C_j = E_j \cdot EC_j = EC_j \cdot CFE_{ipcc-1} \cdot NCV_j \cdot COF_j \quad (23)$$

Where, C_j represents the carbon emissions generated by consuming the j -th type of energy. E_j represents the end-use energy consumption (physical quantity) of the j -th type of energy. EC_j represents the carbon emission factor (physical quantity factor) of the j -th type of energy. CFE_{ipcc-1} represents the default emission factor for carbon emissions from the IPCC₂₀₀₆, which is actually the carbon dioxide emission factor, with the unit of kgCO₂/tJ. NCV_j represents the average lower heating value of the j -th type of energy, with the unit of KJ/Kg or KJ/m³. COF_j represents the carbon oxidation factor, with the value of 0.98 for coal, 0.99 for oil and oil products, and 0.995 for natural gas. The carbon emission factors of the eight primary energy sources are shown in Table 1.

Secondly, calculate the carbon emissions of each province. The energy consumption of raw coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, and natural gas in 30 provinces (except Xizang and Taiwan) was manually summarized and sorted by referring to the *China Energy Statistical Yearbook* of each province. Multiply the values by the corresponding carbon emission coefficients in formula (23), and calculate the carbon emissions of 30 provinces one by one by combining the carbon emission coefficients of each energy source. Table 2 is obtained through sorting, in which the ranking of carbon emissions in 30 provinces is

Table 1
Carbon emission factors of eight primary energy sources.

Fuel type	CFE _{ipcc-1}	NCV _j		COF _j	EC _j	
		Calorific value	Unit		Coefficient	Unit
Raw coal	101,000	20,908	KJ/Kg	0.980	2.069	KgCO ₂ /Kg
Coke	107,000	28,435	KJ/Kg	0.980	2.982	KgCO ₂ /Kg
Crude oil	73,300	41,816	KJ/Kg	0.990	3.034	KgCO ₂ /Kg
Gasoline	74,100	43,070	KJ/Kg	0.990	3.160	KgCO ₂ /Kg
Kerosene	71,500	43,070	KJ/Kg	0.990	3.049	KgCO ₂ /Kg
Diesel oil	74,100	42,652	KJ/Kg	0.990	3.129	KgCO ₂ /Kg
Fuel oil	77,000	41,816	KJ/Kg	0.990	3.188	KgCO ₂ /Kg
Natural gas	56,100	37,259.5	KJ/Kg	0.995	2.080	KgCO ₂ /Kg

Data source: *China Statistical Yearbook*, *China Energy Statistical Yearbook*, *Statistical Resource Compilation of the 60 Years of New China (1949–2008)*.

Table 2

Carbon emissions in 30 provinces (average) (Unit: 10,000 tons).

High carbon emission area			Low carbon emission area		
1	Shandong	122,843.49	16	Sichuan	30,930.85
2	Hebei	86,955.40	17	Guizhou	27,726.63
3	Shanxi	83,270.61	18	Shanghai	25,920.87
4	Jiangsu	75,182.76	19	Jilin	25,311.39
5	Inner Mongolia	73,957.18	20	Fujian	24,471.37
6	Liaoning	70,083.17	21	Yunnan	23,627.85
7	Henan	60,169.45	22	Guangxi	20,578.72
8	Guangdong	58,553.42	23	Jiangxi	19,818.13
9	Zhejiang	43,404.03	24	Gansu	19,125.74
10	Shanxi	40,708.98	25	Ningxia	18,850.56
11	Xinjiang	38,595.11	26	Tianjin	17,505.26
12	Anhui	35,892.17	27	Chongqing	14,200.00
13	Hubei	35,746.71	28	Beijing	10,428.30
14	Heilongjiang	32,803.29	29	Hainan	5163.80
15	Hunan	31,315.48	30	Qinghai	4499.86

shown from 1 to 30. This article divides the provinces with the top 15-carbon emissions into high-carbon emission regions, and the provinces with the bottom 15-carbon emissions into low-carbon emission regions.

Finally, calculate the GDP carbon emission intensity of each province. The formula for GDP carbon emission intensity is:

$$CG = \frac{CO_2}{GDP} \quad (24)$$

3.2.2. Explanatory variable

Green finance. Regarding the green finance indicators, due to the difficulty in obtaining data on green finance at the provincial level, especially the late issuance of green bonds, there is a serious shortage of data. Therefore, based on existing research results, taking into account the actual development of green finance in China and the availability of data, this article draws on the approach of Yu, Liu, and Chen (2023) and selects four dimensions: green credit, green investment, green insurance, and government support. According to the entropy method, the weights of each secondary indicator are determined to construct a green finance index, as shown in Table 3. The data are from the *China Statistical Yearbook*, the *Statistical Yearbooks* of various provinces, and the *China Insurance Yearbook*.

Industrial structure upgrading. According to the characteristics of

Table 3
Construction of green finance indicators.

Primary indicator	Secondary indicator	Characteristic indicator	Indicator description	Attribute
Green finance	Green credit	Proportion of interest in high-energy-consuming industries	Interest expenditure of six high-energy-consuming industries / Total industrial interest expenditure	–
	Green investment	Proportion of investment in environmental pollution control in GDP	Investment in environmental pollution control / GDP	+
	Green insurance	Agricultural insurance depth	Agricultural insurance income / Total agricultural output value	+
	Government support	Proportion of fiscal expenditure on environmental protection	Fiscal expenditure on environmental protection / Fiscal general budget expenditure	–

Table 4
Variable definition and measurement.

	Variable	Symbol	Variable Measure
Dependent variable	GDP carbon emission intensity	CG	Carbon emission / Regional GDP
Explanatory variable	Green finance	GF	Obtained through entropy method
Mediating variable	Industrial structure upgrading	IS	The output value of the tertiary industry / The output value of the secondary industry
	Technological innovation	ZL	Number of patent grants logarithm
	Energy endowment	ESR	Total primary energy production / Total energy consumption
	Population size	People	Logarithm of regional population size
Control variable	Degree of opening up to the outside world Foreign	Open	Direct investment / Gross domestic product
	Urbanization level	Urban	Urban population / Total population
	Educational development level	Edu	Number of college students / Total population
	Price level	CPI	Consumer price index
	Government intervention	Gov	Government fiscal expenditure / Regional GDP

the primary, secondary, and tertiary industries, the primary industry mainly includes agriculture, forestry, animal husbandry, and fishery, with the lowest and most stable carbon emission level, but the capital recovery rate is relatively slow. In terms of labor costs, although the cost expenditure is not high, the return on investment is relatively low. It is currently the most conservative industrial chain, existing as a basic industry, supporting the development of industry and service industries, and to a certain extent, eliminating the surplus labor productivity in rural areas in most parts of China. The secondary industry mainly includes processing and manufacturing, which is the main source of carbon emissions. Although it can achieve a large return on investment and create more jobs, it has a profound impact on the environment and is currently being controlled and developed in a planned manner. Industrial development is inevitably contrary to green finance under the dual carbon goal. The tertiary industry is generally a service industry, which has the highest efficiency in the utilization of human resources. Its advantage lies in its independence from the development and utilization of energy, with the lowest carbon emissions. When the proportion of the tertiary industry in the total industry is larger, the level of industrial structure is higher. This article uses the ratio of the output value of the tertiary industry to the output value of the secondary industry as a proxy variable for the upgrading of the industrial structure, which is used to study the mediating effect of the industrial structure upgrading.

Technological innovation. The measurement of technological innovation can be divided into two types: one is the input variable of technological innovation, namely R&D investment; the other is the output

variable of technological innovation, namely the number of patent licenses and the total transaction volume of technology contracts. In practice, R&D activities often have a high failure rate and strong uncertainty, and R&D investment does not always translate into innovation output. Compared with R&D investment, innovation output can more directly reflect the level of regional innovation (Audretsch & Belitski, 2024). Due to the fact that the total transaction volume of technology contracts in innovation output may have the same technology repeated transactions in different years, this article uses the logarithm of the number of patent licenses of industrial enterprises above designated size in each region as a proxy variable for technological innovation to study the mediating effect of technological innovation.

3.2.3. Control variables

Based on existing literature and the needs of the research questions in this chapter, the following variables were selected as control variables for the model, as shown in Table 4 the sample data was obtained from the CEIC database.

3.3. Descriptive statistics of variables

The sample interval of this article is the annual data from 2006 to 2020. Table 5 is the descriptive statistics of the sample data in this question. It can be seen from the table that the sample size of each variable is 450, and the sample data in this article is a balanced panel structure.

4. Empirical results analysis

4.1. Unit root test for panel data

Before conducting empirical regression analysis on the sample data, it is necessary to conduct panel unit root tests on each variable to avoid spurious regression due to unit root problems. Table 6 shows the unit root test results for each variable, where the ADF unit root test type includes a trend term, an intercept term, and a lag of two orders. The null hypothesis of LLC Test and HT Test is that all units have unit roots (i. e., the data are not stationary). It can be seen from the Table 6 that each variable is statistically significant at the 1% level; therefore, the sample data in this article meets the stationary condition.

4.2. Empirical results analysis

This article uses the estimation method of the system GMM model to estimate the Benchmark Model and mediating effect model. The Table 7 shows the benchmark estimation results, and Table 8 are the empirical estimation results of the mediating effects of industrial structure upgrading and technological innovation. It can be seen from the tables that all models have passed the Sargan test and the AR(2) second-order serial correlation test, indicating that the model instrumental variables are valid and the regression results are not affected by second-order

Table 5
Descriptive Statistics of Sample Data.

Variable	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
CG	450	3.012	2.298	0.210	14.240	2.297
GF	450	0.165	0.140	0.050	0.839	0.105
IS	450	1.202	0.839	0.526	5.310	0.687
ZL	450	9.585	7.824	4.575	13.473	1.619
ESR	450	0.924	0.507	0.005	5.344	1.083
People	450	8.188	8.255	6.306	9.443	0.747
Open	450	0.507	0.241	0.052	33.435	1.634
Urban	450	0.557	0.540	0.275	0.938	0.138
Edu	450	0.019	0.018	0.006	0.041	0.006
CPI	450	2.724	2.370	2.350	10.090	1.785
Gov	450	0.243	0.224	0.095	0.758	0.110

Table 6
LLC, HT and ADF Unit Root Test Results.

Variable	ADF statistic value	LLC statistic value	HT statistic value	Stationary
CG	−6.411(0.000)	−8.286(0.000)	−14.348 (0.000)	steady
GF	−4.163(0.000)	−5.657(0.000)	−10.436 (0.000)	steady
IS	−1.824(0.035)	−15.303(0.000)	−10.197 (0.000)	steady
ZL	−2.175(0.016)	−8.504(0.000)	−9.869(0.000)	steady
ESR	−3.501(0.000)	−11.454(0.000)	−17.023 (0.000)	steady
People	−2.816(0.003)	−13.168(0.000)	−8.575(0.000)	steady
Open	−8.016(0.000)	−18.708(0.000)	−27.952 (0.000)	steady
Urban	−4.127(0.000)	−8.589(0.000)	−12.526 (0.000)	steady
Edu	−9.689(0.002)	−7.677(0.000)	−3.586(0.000)	steady
CPI	−11.794(0.000)	−6.744(0.000)	−15.913 (0.000)	steady
Gov	−4.262(0.000)	−6.489(0.000)	−7.377(0.000)	steady

Note: *P* values are in parentheses.

Table 7
Benchmark Model Estimation Results.

	(1)	(2)	(3)
	Sys-GMM	Diff-GMM	Sys-GMM
L.CG	0.066*** [0.011]	0.049*** [0.010]	−0.092*** [0.013]
GF	−3.035*** [0.773]	−2.534*** [0.618]	−1.973*** [0.618]
CV	Yes	Yes	Yes
N	450	450	450
Sargan	23.463 [1.000]	21.867 [1.000]	20.463 [1.000]
AR(2)	−1.421 [0.155]	−1.249 [0.212]	0.272 [0.786]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

serial correlation. Therefore, the estimation results in this article are reliable.

4.2.1. Benchmark model estimation results

Column (1) in Table 7 tests the total effect of green finance on GDP carbon emission intensity, with a regression coefficient of −3.035, which is statistically significant at the 1% level, indicating that green finance can significantly reduce GDP carbon emission intensity, that is, green finance can assist in the low-carbon transformation of the economy. Hypothesis H1 is verified. Column (2) shows the empirical results estimated using the Difference GMM model, and column (3) shows the empirical results obtained by changing the sample size. From columns (2) and (3), it can be seen that the signs of the coefficients are consistent with column (1), and the absolute values are comparable, indicating that the estimation results in this article are robust and hypothesis H1 is verified.

4.2.2. Estimation results of the mediating effect model

The mediating effect test of industrial structure upgrading:

Firstly, column (1) in Table 8 shows the impact of green finance on industrial structure upgrading, with a regression coefficient of 1.413, which is statistically significant at the 1% level, indicating that green finance can promote industrial structure upgrading. Secondly, column (2) in Table 8 shows the impact of green finance and industrial structure upgrading on GDP carbon emission intensity, of which the regression coefficient of industrial structure upgrading on GDP carbon emission intensity is −0.064, which is statistically significant at the 10% level, indicating that industrial structure upgrading reduces GDP carbon emission intensity. At the same time, after controlling for the industrial

Table 8
Test Results of the Mediating Effect.

Dependent variable	(1) IS	(2) CG	(3) ZL	(4) CG
L.CG		−0.082*** [0.019]		−0.106*** [0.014]
L.IS	0.243*** [0.035]			
L.ZL			0.033 [0.036]	
GF	1.413*** [0.440]	−3.873*** [1.288]	1.911* [1.129]	−1.953*** [0.521]
IS		−0.064* [0.038]		−0.131*** [0.022]
CV	Yes	Yes	Yes	Yes
N	450	450	450	450
Sargan	21.356 [1.000]	20.177 [1.000]	26.684 [1.000]	22.423 [1.000]
AR(2)	1.003 [0.316]	0.394 [0.693]	1.816 [0.169]	0.261 [0.794]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

structure upgrading, the regression coefficient of green finance on GDP carbon emission intensity is −3.873, which is larger in absolute value than the regression coefficient of green finance on GDP carbon emission intensity in the benchmark model (column (1) of Table 7), which is −3.035, and is also statistically significant at the 1% level. Therefore, the path of green finance → industrial structure upgrading → GDP carbon emission intensity exists, and hypothesis H2 is verified. The upgrading of industrial structure plays an intermediary role between green finance and GDP carbon emission intensity, with an impact coefficient of −0.0904 (−0.0640 × 1.4125).

The mediating effect test of technological innovation:

Firstly, column (3) in Table 8 shows the impact of green finance on technological innovation, with a regression coefficient of 1.911, which is statistically significant at the 10% level, indicating that green finance can promote technological innovation. Secondly, column (4) in the table shows the impact of green finance and technological innovation on GDP carbon emission intensity, where the regression coefficient of technological innovation on GDP carbon emission intensity is −0.132, which is statistically significant at the 1% level, indicating that technological innovation can reduce GDP carbon emission intensity. At the same time, after controlling for technological innovation, the regression coefficient of green finance on GDP carbon emission intensity is −1.953, which is less than the regression coefficient of green finance on GDP carbon emission intensity in the benchmark model (column (1) in Table 7), and is also statistically significant at the 1% level. Therefore, there is a path from green finance to technological innovation to GDP carbon emission intensity, and technological innovation plays an intermediary role between green finance and GDP carbon emission intensity. Hypothesis H3 is verified.

5. Further analysis

Due to the significant differences in the level of development and resource endowment among different provinces, it is necessary to consider this difference and conduct heterogeneity analysis during the empirical analysis process. A common classification method is to divide the country into eastern, central, and western regions based on geographical location, but provinces in the same region may also exhibit significant differences in carbon emissions, such as Beijing, which belongs to the eastern region, being a low-carbon emission area, while Hebei Province, also in the eastern region, is a high-carbon emission area. Therefore, this classification method based on geographical location is relatively rough and has limited ability to explain problems. Thus, this study divides high-carbon emission areas and low-carbon emission

Table 9

Test results of mediating effect of industrial structure in high carbon emission regions.

	(1)	(2)	(3)
	CG	IS	CG
L.CG	−0.239*** [0.081]		0.147 [0.150]
L.IS		−0.151 [0.361]	
GF	−19.314* [11.299]	−5.793* [3.215]	−28.821* [15.850]
IS			0.837** [0.415]
CV	Yes	Yes	Yes
N	225	225	225
Sargan	4.087 [1.000]	6.521 [1.000]	4.652 [1.000]
AR(2)	0.179 [0.858]	1.501 [0.133]	−1.555 [0.120]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

areas based on differences in carbon emissions for heterogeneity testing.¹

5.1. High carbon emission areas

Tables 9 and 10 respectively show the empirical estimation results of the mediating effects of industrial structure upgrading and technological innovation in high-carbon emission regions. The mediating effect test of industrial structure:

Firstly, column (1) in Table 9 examines the total effect of green finance on GDP carbon emission intensity in high carbon emission regions, with a regression coefficient of −19.314, which is statistically significant at the 10% level, indicating that green finance can significantly reduce GDP carbon emission intensity in high carbon emission regions. That is, green finance can help the economy transition to low carbon. Hypothesis H1 is verified. Secondly, column (2) in the table examines the impact of green finance on the upgrading of industrial structure in high carbon emission regions, with a regression coefficient of −5.793, which is statistically significant at the 10% level, indicating that green finance is not conducive to the upgrading of the industrial structure in high carbon emission regions. Finally, column (3) in the table examines the impact of green finance and upgrading of industrial structure on GDP carbon emission intensity in high carbon emission regions. Among them, the regression coefficient of industrial structure upgrading on GDP carbon emission intensity is 0.837, which is statistically significant at the 5% level, indicating that the upgrading of the industrial structure in high carbon emission regions cannot reduce GDP carbon emission intensity. At the same time, after controlling for the upgrading industrial structure, the regression coefficient of green finance on GDP carbon emission intensity is −28.821, which is larger in absolute value than the regression coefficient of green finance on GDP carbon emission intensity in column (1), and is statistically significant at the 10% level. Therefore, there is a path of green finance→upgrading of industrial structure→GDP carbon emission intensity in high carbon emission regions. The upgrading of industrial structure plays a negative mediating role between green finance and GDP carbon emission intensity, and hypothesis H2 is verified.

The mediating effect test of technological innovation:

Firstly, column (1) in Table 10 examines the total effect of green finance on GDP carbon emission intensity in high-carbon emission regions, with a regression coefficient of −19.314 and a significant level of 10%. This indicates that green finance can significantly reduce GDP carbon emission intensity in high-carbon emission regions, which supports the hypothesis that green finance can assist in the low-carbon transformation of the economy. Secondly, column (2) in the table examines the impact of green finance on technological innovation in high-

Table 10

The mediating effect test results of technological innovation in high carbon emission regions.

	(1)	(2)	(3)
	CG	ZL	CG
L.CG	−0.239*** [0.081]		0.059 [0.236]
L.ZL		−0.283* [0.157]	
GF	−19.314* [11.299]	23.812*** [5.901]	−10.783* [13.392]
ZL			−0.066* [0.147]
CV	Yes	Yes	Yes
N	225	225	225
Sargan	4.087 [1.000]	4.316 [1.000]	0.527 [1.000]
AR(2)	0.179 [0.858]	−0.251 [0.802]	−1.431 [0.152]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

carbon emission regions, with a regression coefficient of 23.812 and a significant level of 1%. This indicates that green finance can promote technological innovation in high-carbon emission regions. Finally, column (3) in the table examines the impact of green finance and technological innovation on GDP carbon emission intensity in high-carbon emission regions. Among them, the regression coefficient of technological innovation on GDP carbon emission intensity is −0.066, which is significant at the 10% statistical level. This indicates that technological innovation can reduce GDP carbon emission intensity. At the same time, after controlling for technological innovation, the regression coefficient of green finance on GDP carbon emission intensity is −10.783, which is significantly lower than the regression coefficient of green finance on GDP carbon emission intensity in column (1) at the 10% statistical level. Therefore, there is a path from green finance to R&D investment to GDP carbon emission intensity in high-carbon emission regions. R&D investment plays a positive mediating role between green finance and GDP carbon emission intensity, which supports the hypothesis that H3 is verified.

5.2. Low-carbon emission areas

Tables 11 and 12 present the empirical estimation results of the mediating effect of industrial structure upgrading and technological innovation in low-carbon emission regions. The mediating effect test of industrial structure:

Firstly, column (1) in Table 11 is the total effect of green finance on GDP carbon emission intensity in low-carbon emission regions, with a regression coefficient of −10.024, which is statistically significant at the 5% level, indicating that green finance can significantly reduce GDP carbon emission intensity in low-carbon emission regions. That is, green finance can assist in the low-carbon transformation of the economy, which verifies hypothesis H1. Secondly, column (2) in the table is the impact of green finance on the industrial structure upgrading in low-carbon emission regions, with a regression coefficient of 1.423, which

Table 11

The mediating effect test results of the industrial structure in low-carbon emission regions.

	(1)	(2)	(3)
	CG	IS	CG
L.CG	−0.118 [0.135]		0.128** [0.052]
L.IS		0.305 [0.277]	
GF	−10.024** [4.891]	1.423* [3.594]	−3.132* [1.698]
IS			−0.397* [0.211]
CV	Yes	Yes	Yes
N	225	225	225
Sargan	2.841 [1.000]	3.983 [1.000]	1.919 [1.000]
AR(2)	−1.420 [0.156]	−1.526 [0.127]	−1.206 [0.140]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

¹ The division of high-carbon emission areas and low-carbon emission areas is detailed in Table 2 of the research design in Chapter 3 of this article.

Table 12

The mediating effect test results of technological innovation in low-carbon emission regions.

	(1)	(2)	(3)
	CG	ZL	CG
L.CG	−0.118 [0.135]		0.052 [0.148]
L.ZL		0.944 [0.846]	
GF	−10.024** [4.891]	22.462* [13.219]	−42.792** [19.985]
ZL			−0.207* [0.121]
CV	Yes	Yes	Yes
N	225	225	225
Sargan	2.841 [1.000]	1.783 [1.000]	0.366 [1.000]
AR(2)	−1.420 [0.156]	0.556 [0.578]	−1.389 [0.165]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

is statistically significant at the 10% level, indicating that green finance can promote the upgrading of the industrial structure in low-carbon emission regions. Finally, column (3) in the table is the impact of green finance and upgrading of industrial structure on GDP carbon emission intensity in low-carbon emission regions, where the regression coefficient of industrial structure on GDP carbon emission intensity is -0.397 , which is statistically significant at the 10% level, indicating that the upgrading of the industrial structure in low-carbon emission regions can reduce GDP carbon emission intensity. At the same time, after controlling for the industrial structure upgrading, the regression coefficient of green finance on GDP carbon emission intensity is -3.132 , which is less than the regression coefficient of green finance on GDP carbon emission intensity in column (1), and is statistically significant at the 5% level. Therefore, there is a path of green finance→industrial structure upgrading→GDP carbon emission intensity in low-carbon emission regions. The industrial structure plays a positive mediating role between green finance and GDP carbon emission intensity, which verifies hypothesis H2.

The mediating effect test of technological innovation:

Firstly, column (1) in Table 12 examines the total effect of green finance on GDP carbon emission intensity in low-carbon emission regions, with a regression coefficient of -10.024 , which is statistically significant at the 5% level, indicating that green finance can significantly reduce GDP carbon emission intensity in low-carbon emission regions. That is, green finance can assist in the low-carbon transformation of the economy, which verifies hypothesis H1. Secondly, column (2) in the table examines the impact of green finance on technological innovation in low-carbon emission regions, with a regression coefficient of 22.462 , which is statistically significant at the 10% level, indicating that green finance can promote technological innovation in low-carbon emission regions. Finally, column (3) in the table examines the impact of green finance and technological innovation on GDP carbon emission intensity in low-carbon emission regions, where the regression coefficient of technological innovation on GDP carbon emission intensity is -0.207 , which is statistically significant at the 10% level, indicating that technological innovation can reduce GDP carbon emission intensity. At the same time, after controlling for technological innovation, the regression coefficient of green finance on GDP carbon emission intensity is -42.792 , which is significantly larger than the regression coefficient of green finance on GDP carbon emission intensity in column (1), and also statistically significant at the 5% level. Therefore, there is a path from green finance to technological innovation to GDP carbon emission intensity in low-carbon emission regions. Technological innovation plays a positive mediating role between green finance and GDP carbon emission intensity, which verifies hypothesis H3.

5.3. Robustness test

To further investigate the reliability of the conclusion, this article

uses the methods of changing estimation methods and sample size for robustness testing. The robustness testing regression results are basically consistent with the previous conclusions, indicating that the conclusions of this article are relatively reliable. Due to space limitations, the table is not listed (see Appendix for details).

6. Research conclusions and policy suggestions

6.1. Research conclusions

Based on the green Solow model constructed by Brock and Taylor (2010), this article innovatively introduces the green finance factor to expand the model, mathematically deriving that green finance can help the low-carbon transformation of the economy, and systematically analyzing the industrial structure path and technological innovation path of green finance in assisting the low-carbon transformation of the economy. In terms of empirical evidence, based on the panel data of 30 provinces (cities) from 2006 to 2020, this article constructs an intermediary effect model and a GMM model to test the industrial structure path and technological innovation path of green finance in assisting the low-carbon transformation of the economy. Through the research of this article, the following conclusions are drawn:

First, green finance can significantly reduce the GDP carbon emission coefficient, which means that green finance can help the economy transition to low carbon. The mediating effect model test found that there are paths from green finance to upgrading of industrial structure and GDP carbon emission intensity, as well as from green finance to technological innovation and GDP carbon emission intensity.

Second, there is regional heterogeneity in the industrial structure and technological innovation path of green finance in supporting low-carbon economic transformation: in high-carbon emission regions, green finance is not conducive to upgrading the industrial structure, and it plays a negative mediating role in the process of green finance supporting low-carbon economic transformation. In addition, both the technological innovation path in high-carbon emission regions and the upgrading of industrial structure and technological innovation path in low-carbon emission regions play a positive mediating role in the process of green finance supporting low-carbon economic transformation.

6.2. Policy suggestions

Firstly, we should strengthen the concept of green development and actively improve the green financial system. Green finance is the key to achieving green economic development and an important measure to support low-carbon economic transformation and sustainable development. We should fully recognize the importance of green finance, strengthen the concept of green development, and actively improve the existing green financial system. On the one hand, we should innovate green financial products and gradually expand the product design to green industrial and clean energy, including loans for nuclear power, hydropower, solar power and photovoltaic power generation projects. On the other hand, we should actively guide different types of financial institutions to penetrate into the development of green finance. In addition to the main participants of commercial banks, we should encourage and guide securities, funds, trusts and other financial institutions to play an active role in the development of green finance, improve the participation of various financial institutions, and accelerate the establishment of diversified green financial entities.

Secondly, reducing the proportion of pollution-intensive industries in low-carbon emission areas and promoting the upgrading of industrial structure. Green finance can help the low-carbon transformation of the economy in low-carbon emission areas through the upgrading of industrial structure. To this end, on the one hand, we should formulate relevant credit policies to promote the development of low-carbon industries and vigorously support low-carbon enterprises and projects with development potential. On the other hand, we should accelerate

the elimination of backward production capacity in low-carbon emission areas, actively carry out the “green” transformation of traditional industries, and promote the low-carbon transformation of the economy.

Finally, we should improve the level of technological innovation in high-carbon emission regions and promote the transformation of economic growth mode to intensive mode. First, we should promote the integrated development of green finance and technological innovation in high-carbon emission regions, reduce the comprehensive energy consumption level of industry enterprises, and find a low-carbon development model that is more compatible with the industrial

structure of high-carbon emission regions. Second, we should use financial policies to alleviate the financing constraints of green innovative enterprises, promote low-carbon technological innovation and emission reduction equipment transformation, and promote green development in the region.

Data availability

Data will be made available on request.

Appendix A. Appendix

(1) Robustness test 1: using the difference GMM method.

This article uses the replacement estimation method to conduct a robustness test. The replacement estimation method is the difference GMM method. Tables 13 to 18 are estimated and show little difference from the empirical results in Tables 7 to 12 above, indicating that the empirical results in this chapter are robust.

The mediating effect test results of industrial structure (Robustness Test 1).

	CG	IS	CG
	(1)	(2)	(3)
L_CG	0.0486*** [0.0101]		−0.1038*** [0.0093]
L_IS		0.1986*** [0.0295]	
GF	−2.5339*** [0.6177]	1.8642*** [0.6926]	−1.3732** [0.5333]
IS			−0.0215* [0.0547]
ESR	−0.6591*** [0.0177]	0.0107 [0.0105]	−0.6738*** [0.0207]
People	0.5083 [0.7137]	−1.3758* [0.7911]	2.6751 [2.3733]
Open	−0.0027*** [0.0010]	0.0015*** [0.0003]	−0.0045*** [0.0007]
Urban	0.1796 [0.4677]	0.0342 [0.1447]	0.5949 [0.4443]
Edu	0.1198** [0.0504]	−0.1938*** [0.0335]	0.2053 [0.1335]
CPI	−0.0161*** [0.0018]	−0.0048*** [0.0006]	−0.0085*** [0.0019]
Gov	1.0563** [0.4235]	1.1806*** [0.1373]	1.6430*** [0.5943]
_cons	−0.0048*** [0.0007]	0.0009*** [0.0003]	−0.0106*** [0.0012]
N	450	450	450
Sargan	21.8667 [1.0000]	18.8252 [1.0000]	20.0989 [1.0000]
AR(2)	−1.2492 [0.2116]	0.8974 [0.3695]	0.6046 [0.5454]

Note: *, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of technological innovation (Robustness Test 1).

	CG	ZL	CG
	(1)	(2)	(3)
L_CG	0.0486*** [0.0101]		−0.1237*** [0.0100]
L_ZL		0.0039 [0.0293]	
GF	−2.5339*** [0.6177]	1.9759** [0.9142]	−1.1485* [0.6462]
ZL			−0.1158*** [0.0174]
ESR	−0.6591*** [0.0177]	0.1859*** [0.0238]	−0.6019*** [0.0212]

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	CG	ZL	CG
	(1)	(2)	(3)
People	0.5083 [0.7137]	−1.6023 [3.0328]	2.1401* [1.2945]
Open	−0.0027*** [0.0010]	0.0126*** [0.0020]	−0.0055*** [0.0012]
Urban	0.1796 [0.4677]	3.7886 [2.9644]	0.9732** [0.3952]
Edu	0.1198** [0.0504]	0.2384 [0.1626]	0.1133* [0.0584]
CPI	−0.0161*** [0.0018]	−0.0023 [0.0016]	−0.0090*** [0.0024]
Gov	1.0563** [0.4235]	1.8297*** [0.5097]	1.3510** [0.5409]
_cons	−0.0048*** [0.0007]	0.0009 [0.0008]	−0.0105*** [0.0012]
N	450	450	450
Sargan	21.8667 [1.0000]	27.2350 [0.9999]	20.6791 [1.0000]
AR(2)	−1.2492 [0.2116]	1.7418 [0.8151]	0.5039 [0.6144]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of the industrial structure in high carbon emission regions (Robustness Test 1).

	CG	IS	CG
	(1)	(2)	(3)
L_CG	−0.2574** [0.1094]		−0.1277** [0.0577]
L_IS		−0.1221 [0.1276]	
GF	−12.5182* [13.3678]	−5.0356* [7.3382]	−22.9749* [40.1828]
IS			0.5533* [0.4626]
ESR	−0.2958*** [0.0934]	−0.0531 [0.0914]	−0.2635*** [0.0426]
People	−12.1806 [8.4694]	17.1879 [16.2197]	−9.8658 [15.8511]
Open	1.0050** [0.4629]	0.1726 [0.1620]	0.6484 [0.5504]
Urban	5.7676 [16.1565]	0.3436 [1.3681]	12.7523 [18.3726]
Edu	−0.275 [0.3270]	0.6632 [0.7402]	−0.3936 [0.7249]
CPI	−0.0013 [0.0145]	−0.0090*** [0.0035]	−0.0091 [0.0130]
Gov	−2.7114 [5.7202]	1.4189** [0.5790]	0.2414 [3.7994]
_cons	−0.0247** [0.0110]	−0.0060* [0.0036]	−0.0117 [0.0092]
N	225	225	225
Sargan	7.2656 [1.0000]	7.1214 [1.0000]	7.6437 [1.0000]
AR(2)	−0.9839 [0.3252]	−1.0669 [0.2860]	−0.4454 [0.6561]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of technological innovation in high carbon emission regions (Robustness Test 1).

	CG	ZL	CG
	(1)	(2)	(3)
L_CG	−0.2574** [0.1094]		0.0146 [0.2814]
L_ZL		−0.1762 [0.1945]	
GF	−12.5182* [13.3678]	15.0796* [11.8638]	−8.0724* [18.5355]

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	CG	ZL	CG
	(1)	(2)	(3)
ZL			−0.0673* [0.2013]
ESR	−0.2958*** [0.0934]	0.1365 [0.1183]	−0.5371*** [0.1999]
People	−12.1806 [8.4694]	−22.0602 [19.6580]	1.3799 [5.6212]
Open	1.0050** [0.4629]	0.2151 [0.2729]	0.4230 [0.3113]
Urban	5.7676 [16.1565]	16.6535* [9.2601]	−12.1554 [12.5451]
Edu	−0.275 [0.3270]	−0.8337 [0.8466]	0.4149 [0.6424]
CPI	−0.0013 [0.0145]	−0.0098 [0.0074]	0.0024 [0.0124]
Gov	−2.7114 [5.7202]	4.2478* [2.2498]	4.8456 [2.9886]
_cons	−0.0247** [0.0110]	0.0061** [0.0025]	−0.0157*** [0.0054]
N	225	225	225
Sargan	7.2656 [1.0000]	6.0787 [1.0000]	5.8712 [1.0000]
AR(2)	−0.9839 [0.3252]	−0.0624 [0.9503]	−0.2355 [0.8138]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

Test results of the mediating effect of industrial structure in low-carbon emission regions (Robustness Test 1).

	CG	IS	CG
	(1)	(2)	(3)
L.CG	0.0081 [0.0833]		0.0735 [0.0641]
L.IS		0.1631 [0.1718]	
GF	−12.5873** [6.2021]	1.3298* [2.4653]	−3.0516* [2.1889]
IS			−0.3590* [0.2262]
ESR	−0.7708*** [0.1343]	0.0213 [0.0481]	−0.7069*** [0.1350]
People	−8.393 [11.5962]	−0.7775 [5.7594]	−0.7829 [2.7010]
Open	−0.0171* [0.0103]	0.0022 [0.0017]	−0.0087 [0.0087]
Urban	−6.3132 [14.3311]	−2.5117 [2.1168]	1.2566 [2.0639]
Edu	−0.2123 [0.4985]	−0.1273 [0.1706]	0.0711 [0.3565]
CPI	−0.0270* [0.0162]	−0.0040** [0.0018]	−0.0284*** [0.0075]
Gov	−5.6138 [6.9479]	0.5410* [0.3007]	−2.1928** [0.9544]
_cons	−0.0051 [0.0054]	−0.0003 [0.0008]	0.0003 [0.0100]
N	225	225	225
Sargan	7.5304 [1.0000]	6.5486 [1.0000]	5.0289 [1.0000]
AR(2)	0.7690 [0.4419]	−0.3272 [0.7435]	−1.2534 [0.2101]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of technological innovation in low-carbon emission regions (Robustness Test 1).

	CG	ZL	CG
	(1)	(2)	(3)
L.CG	0.0081 [0.0833]		0.2132 [0.2429]

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(continued)

	CG	ZL	CG
	(1)	(2)	(3)
L_ZL		0.1063 [0.7016]	
GF	−12.5873** [6.2021]	20.0096* [21.1178]	−24.9665** [11.8095]
ZL			−0.2186*** [0.0723]
ESR	−0.7708*** [0.1343]	0.4181 [0.5911]	−0.6463** [0.2681]
People	−8.393 [11.5962]	−230 [218.1002]	−60.5874* [32.5961]
Open	−0.0171* [0.0103]	0.0155*** [0.0057]	−0.0244** [0.0102]
Urban	−6.3132 [14.3311]	124.235 [148.2266]	−9.8157 [14.3216]
Edu	−0.2123 [0.4985]	0.8308 [1.5365]	−2.3121 [1.4134]
CPI	−0.0270* [0.0162]	−0.1022 [0.1062]	−0.0503** [0.0204]
Gov	−5.6138 [6.9479]	−14.4813 [18.3994]	−6.5369 [4.6132]
_cons	−0.0051 [0.0054]	−0.0291 [0.0459]	0.0037 [0.0105]
N	225	225	225
Sargan	7.5304 [1.0000]	0.7149 [1.0000]	1.7846 [1.0000]
AR(2)	0.7690 [0.4419]	−0.4003 [0.6889]	−0.5783 [0.5631]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

(2) Robustness test 2: adding control variables to change the sample size.

This chapter adopts the method of adding control variables to change the sample size for robustness testing. The added control variable is government fiscal capacity (GOV), which is represented by government fiscal revenue/gross regional product. The reason for selecting government fiscal capacity as the new control variable is that the current development of green finance still depends on the support of local governments. Estimates are shown in Tables 19 to 24, which show little difference from the empirical results in Tables 7 to 12 above, indicating that the empirical results in this chapter are robust.

Test results of the mediating effect of industrial structure (Robustness Test 2).

	CG	IS	CG
	(1)	(2)	(3)
L_CG	−0.0919*** [0.0131]		0.0892*** [0.0134]
L_IS		0.1766*** [0.0288]	
GF	−1.9734*** [0.6179]	1.5171* [0.5145]	−2.9285** [0.8429]
IS			−0.0730* [0.0835]
ESR	−0.7367*** [0.0132]	0.0228 [0.0142]	−0.6814*** [0.0300]
People	2.3483 [1.8456]	−2.1595*** [0.6293]	0.9076 [1.5935]
Open	−0.0074*** [0.0009]	0.0021*** [0.0005]	0.0038** [0.0017]
Urban	−0.6722 [1.2835]	−0.2316 [0.1450]	0.2600 [0.5500]
Edu	0.1769* [0.1060]	−0.2804*** [0.0284]	0.1924*** [0.0521]
CPI	−0.0087*** [0.0027]	−0.0039*** [0.0006]	−0.0204*** [0.0026]
Gov	−0.5222 [0.3811]	0.9649*** [0.1845]	0.2354 [0.5136]
GOV	−2.6864*** [0.2706]	−0.0183 [0.0894]	−1.0406*** [0.1492]
_cons	−0.0098*** [0.0009]	0.0001 [0.0002]	−0.0043*** [0.0004]
N	450	450	450
Sargan	20.4630 [1.0000]	22.0751 [1.0000]	21.3697 [1.0000]
AR(2)	0.2717 [0.7859]	0.3970 [0.6914]	0.3951 [0.6928]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

Test results of the mediating effect of technological innovation (Robustness Test 2).

	CG	ZL	CG
	(1)	(2)	(3)
L.CG	−0.0919*** [0.0131]		−0.1213*** [0.0196]
L.ZL		0.0940** [0.0456]	
GF	−1.9734*** [0.6179]	1.3931* [1.0963]	−1.5280* [2.2400]
ZL			−0.1165*** [0.0180]
ESR	−0.7367*** [0.0132]	0.2906*** [0.0274]	−0.6174*** [0.0282]
People	2.3483 [1.8456]	−2.6105 [2.3989]	1.9377 [2.6551]
Open	−0.0074*** [0.0009]	0.0140*** [0.0026]	−0.0066*** [0.0012]
Urban	−0.6722 [1.2835]	4.0850** [1.9849]	1.7741 [1.2125]
Edu	0.1769* [0.1060]	0.2901** [0.1293]	0.1867 [0.1153]
CPI	−0.0087*** [0.0027]	0.0003 [0.0019]	−0.0098*** [0.0027]
Gov	−0.5222 [0.3811]	1.7521*** [0.2974]	0.3878 [0.5997]
GOV	−2.6864*** [0.2706]	−0.4432** [0.2046]	−1.5772*** [0.2971]
_cons	−0.0098*** [0.0009]	−0.0033*** [0.0007]	−0.0111*** [0.0010]
N	450	450	450
Sargan	20.4630 [1.0000]	27.0745 [0.9999]	18.7672 [1.0000]
AR(2)	0.2717 [0.7859]	0.7780 [0.4366]	0.9984 [0.3181]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of the industrial structure in high carbon emission regions (Robustness Test 2).

	CG	IS	CG
	(1)	(2)	(3)
L.CG	−0.1248** [0.0496]		0.2855 [0.4049]
L.IS		−0.5217*** [0.2013]	
GF	−21.3611* [14.5931]	−4.0052* [3.0973]	−20.8045* [10.9580]
IS			0.7642** [0.6929]
ESR	−0.2284** [0.1056]	0.0673** [0.0282]	−0.6660* [0.3625]
People	−2.2455 [3.9069]	−10.7784*** [4.0519]	3.888 [18.2829]
Open	0.6439* [0.3425]	0.0050 [0.0469]	0.7640** [0.3780]
Urban	−1.7117 [5.2152]	−0.0003 [0.5048]	16.6245 [21.0225]
Edu	−0.1338 [0.2455]	−0.5859*** [0.2227]	0.0648 [2.9206]
CPI	−0.0161 [0.0133]	−0.0052*** [0.0011]	−0.0260 [0.0195]
Gov	−4.6135 [5.7053]	1.1913*** [0.3644]	−3.3883 [2.5321]
GOV	−1.677 [1.2623]	−0.1938 [0.1442]	−1.5228** [0.5918]
_cons	−0.0076*** [0.0018]	−0.0008 [0.0008]	0.0021 [0.0077]
N	225	225	225

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	CG	IS	CG
	(1)	(2)	(3)
Sargan	5.6839 [1.0000]	4.8055 [1.0000]	3.7893 [1.0000]
AR(2)	−0.0702 [0.9440]	0.3866 [0.6991]	−0.4576 [0.6473]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of technological innovation in high carbon emission regions (Robustness Test 2).

	CG	ZL	CG
	(1)	(2)	(3)
L.CG	−0.1248** [0.0496]		−0.3583*** [0.1125]
L.ZL		−0.1661* [0.1325]	
GF	−21.3611* [14.5931]	20.5380*** [7.4130]	−14.9192* [18.1678]
ZL			−0.0258* [0.1677]
ESR	−0.2284** [0.1056]	0.052 [0.0983]	−0.1833 [0.2146]
People	−2.2455 [3.9069]	−10.8555 [18.0928]	−27.3370 [28.2391]
Open	0.6439* [0.3425]	0.1157 [0.2671]	0.4847 [0.4777]
Urban	−1.7117 [5.2152]	10.2935 [9.2460]	13.9676 [9.8727]
Edu	−0.1338 [0.2455]	−0.1863 [0.7970]	−1.8341 [1.4889]
CPI	−0.0161 [0.0133]	−0.0033 [0.0085]	−0.0149 [0.0111]
Gov	−4.6135 [5.7053]	0.7817 [2.1861]	−4.8252 [4.2556]
GOV	−1.677 [1.2623]	0.2783 [0.8923]	−2.6212** [1.2906]
_cons	−0.0076*** [0.0018]	0.0039* [0.0024]	−0.0077* [0.0044]
N	225	225	225
Sargan	7.2656 [1.0000]	6.0787 [1.0000]	5.8712 [1.0000]
AR(2)	−0.9839 [0.3252]	−0.0624 [0.9503]	−0.2355 [0.8138]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of the industrial structure in low-carbon emission regions (Robustness Test 2).

	CG	IS	CG
	(1)	(2)	(3)
L.CG	−0.1178 [0.1349]		0.1242** [0.0494]
L.IS		0.0387* [0.1589]	
GF	−10.0273** [4.8905]	1.3696* [3.9912]	−2.7554* [1.6491]
IS			−0.3896* [0.1992]
ESR	−0.5971** [0.2550]	−0.0707 [0.0978]	−0.8175*** [0.1040]
People	39.0238 [29.8222]	−9.9937 [10.1765]	−0.5759 [2.2047]
Open	−0.0291 [0.0233]	0.0048** [0.0022]	−0.0029 [0.0075]
Urban	13.7624 [16.5104]	−4.5201 [4.0961]	0.3535 [1.5229]
Edu	1.2067 [0.9031]	−0.4894** [0.2398]	0.0692 [0.2850]

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	CG	IS	CG
	(1)	(2)	(3)
CPI	0.0108 [0.0167]	−0.0049** [0.0019]	−0.0297*** [0.0062]
Gov	3.9458 [7.2255]	0.8197*** [0.2254]	−1.4205* [0.7887]
GOV	−6.2875* [3.4595]	0.2035 [0.3675]	−1.3734*** [0.3689]
_cons	−0.0172** [0.0070]	0.0014* [0.0008]	−0.002 [0.0099]
N	225	225	225
Sargan	2.8403 [1.0000]	3.8691 [1.0000]	5.0289 [1.0000]
AR(2)	−1.4203 [0.1555]	−1.7440 [0.8120]	−1.2534 [0.2101]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

The mediating effect test results of technological innovation in low-carbon emission regions (Robustness Test 2).

	CG	ZL	CG
	(1)	(2)	(3)
L.CG	0.1467*** [0.0309]		0.0515 [0.1479]
L.ZL		0.9775* [0.8522]	
GF	−12.0402* [9.2157]	22.3324* [13.3025]	−42.7924** [19.9962]
ZL			−0.2064* [0.1207]
ESR	−0.6927*** [0.1049]	−0.9504* [0.5656]	−0.5378** [0.2275]
People	13.0009 [20.4908]	−1.6e+02** [76.1219]	−22.5168 [19.4026]
Open	−0.0160* [0.0087]	0.0136*** [0.0040]	−0.0312* [0.0172]
Urban	3.438 [4.4717]	−33.1229 [22.2932]	−9.4389 [18.1624]
Edu	0.4479 [0.7069]	3.1279*** [1.2000]	−0.4666 [0.9920]
CPI	−0.0198* [0.0119]	−0.0329 [0.0249]	−0.0161 [0.0145]
Gov	−3.3686*** [1.2623]	−4.5895 [5.7435]	0.3541 [5.2226]
GOV	−3.5139* [1.9680]	1.2683 [3.4226]	−9.0856*** [3.3320]
_cons	−0.0005 [0.0074]	0.0317** [0.0143]	−0.0115 [0.0073]
N	225	225	225
Sargan	6.9705 [1.0000]	1.7674 [1.0000]	0.3659 [1.0000]
AR(2)	0.9776 [0.3283]	−1.6037 [0.1088]	−1.3883 [0.1650]

Note:*, **, *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively. The standard error is shown in parentheses.

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