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The Impact of Carbon Finance Development Level on China's Provincial Low-Carbon Transition

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Abstract: *This study explores the role of carbon finance in provincial low-carbon transformation in China, in line with dual carbon goals. Using panel data from 30 provincial regions (2012-2021) and a Spatial Durbin Model, it analyzes how carbon finance development affects low-carbon transformation. Results show that carbon finance positively influences low-carbon transformation nationally, with notable spatial heterogeneity. In Central and Eastern China, carbon finance significantly advances local low-carbon transformation and positively affects neighboring areas. However, in Western China, its impact is less significant and negatively influences nearby regions.*

Keywords: *Carbon Finance Evaluation, Urban Low-Carbon Transition, Spatial Econometric Model*

1. Introduction

As the world's largest energy consumer and carbon emitter, how to effectively reduce carbon emissions and achieve urban low-carbon transformation while maintaining high-quality economic development has become an extremely important practical issue facing China. Developed countries at the mature stage of industrialization have unanimously chosen the same path to effectively reduce carbon emissions: establishing carbon markets and developing carbon finance. Carbon finance refers to a series of financial instruments aimed at reducing greenhouse gas emissions and mitigating climate change by pricing carbon emissions. Its concept emerged with the establishment of carbon emission trading markets, and its connotation has been enriched with the development of carbon markets. After eight local carbon market pilots in cities, a unified carbon market covering China was officially launched on December 19, 2017. As an emerging derivative, how does the "localized" development of carbon finance in China affect the low-carbon transformation of provinces? Can it have an immediate effect similar to that in developed countries? Additionally, given China's vast territory and significant internal provincial differences, is there regional variation in the impact of carbon finance development on low-carbon transformation? Exploring these questions is crucial for formulating localized carbon finance development policies in China and accelerating provincial low-carbon transformations.

2. Literature Review

In China, numerous scholars have established distinctive evaluation systems for low-carbon cities and conducted related research. Fan et al. (2009) [1] evaluated the transformation of resource cities from the perspective of industrial development, considering aspects like resource utilization, ecological environment, and social development. They set up indicators related to systemic innovation to evaluate its impact on urban transformation, but their study did not conduct empirical analysis. Cheng et al. (2009) [2], in her research on the transformation effects of resource-exhausted cities in China, treated transformation policies as dummy variables and used fixed-effect models to analyze their impact on per capita GDP and living standards. The results indicated that the effects of transformation policies were not significant, and she offered policy recommendations. Tan et al. (2014) [3] introduced a capability maturity model in the evaluation system for low-carbon transformation of resource-based cities, selecting policy maturity, industry maturity, environmental maturity, and technological maturity as primary indicators and their corresponding secondary indicators. They assessed Datong and Anshan cities and provided suggestions for model improvement. Overall, the evaluation indicators mostly focus on economic, social, environmental, scientific, and policy aspects.

Regarding the impact of carbon finance development on urban low-carbon transformation, Fan et al.

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(2003) [4] used Marxist reproduction theory and Patinkin's "demand following" and "supply leading" theories to derive the internal mechanism of financial structure evolution and industrial structure upgrading. El-Karmi et al. (2013) [5] argued that the widespread trading of green credit products in the carbon finance market can provide financial support for low-carbon economic development, improve energy utilization, and promote urban low-carbon transformation. Peng et al. (2019) [6] analyzed the transmission mechanism of carbon finance in promoting industrial structure adjustment from three perspectives: carbon finance trading mechanism, commercial banking industry, and corporate strategy adjustment. They concluded that studying carbon finance trading mechanisms helps adjust the industrial structure of cities, transform economic growth models, and drive low-carbon transformation. Minh et al. (2022) [7] focused on green bonds, asserting that acquiring green technology can achieve effective energy transformation and sustainable development goals.

Compared to existing literature, this paper's innovation lies in two aspects: firstly, it analyzes the potential impact of carbon finance on provincial low-carbon transformation by constructing an evaluation system for provincial low-carbon transformation, linking the emerging derivative of carbon finance with provincial low-carbon transformation. Most literature tends to limit the impact of carbon finance to its effects on green technology and traditional finance, overlooking its macro-level impact on provincial low-carbon transformation. Secondly, this paper analyzes the different impacts of carbon finance development in different economic zones of China, reflecting the heterogeneity in the impact of carbon finance on low-carbon transformation at the provincial level, an aspect largely neglected in previous literature on the subject.

3. Theoretical Analysis and Research Hypotheses

Carbon finance, by integrating market mechanisms and financial tools, provides cities with avenues to attract green investment, innovate technology, and pursue sustainable development projects. On one hand, carbon finance can promote the expansion of green credit, forming a fund guidance mechanism [8]. By offering more credit benefits to energy-saving and emission-reduction projects, it provides more funds for low-carbon industries, guiding urban low-carbon transformation and optimization of industrial structures. On the other hand, by establishing and improving carbon finance trading markets, it facilitates the efficient allocation of resources and accelerates the process of urban low-carbon transformation. Additionally, the development of carbon finance can induce healthy competition among industries, foster product innovation, and provide technical support for urban low-carbon transformation [9]. This not only reduces regional carbon emissions, improves air quality and ecological environment, but also helps regions improve energy efficiency, promote the adoption of clean energy, encourage low-carbon transportation, and other low-carbon measures, thereby laying a solid foundation for China's sustainable regional development. Therefore, Hypothesis 1 is proposed:

H1: The development of carbon finance contributes to provincial low-carbon transformation.

Given China's vast territory and the significant differences in economic development and financial industry development levels across regions, the development of carbon finance, as a financial derivative, also varies considerably. In Central and Eastern China, the development of carbon finance can significantly promote low-carbon transformation within these provinces, as the financial industry has formed a relatively mature and complete system. These areas, with increasingly diversified and service-oriented economic structures, possess strong capital flow and technological innovation capabilities, providing a realistic basis for the development of carbon finance. With the advancement of carbon finance, these regions can effectively limit excess carbon emissions through market mechanisms, thereby playing a positive demonstration effect on the national low-carbon transformation. However, in Western and Northeastern China, the development of carbon finance does not significantly impact provincial low-carbon transformation. The reason lies in the Western region's long-term economic growth based primarily on the extraction and consumption of fossil fuels. This investment structure not only leads to a continuous increase in carbon emissions but also exacerbates the economic dependence on traditional energy sources, posing significant obstacles to low-carbon transformation. In the Northeast, as the country's old industrial base, there is a large accumulation of traditional industries and related infrastructure. These enterprises and facilities may be relatively backward in technology and management, facing significant pressure to meet national low-carbon emission standards. The funds and technology required for technological upgrades and transformations are substantial. Although carbon finance can provide some financial support for these enterprises, due to the industrial structure and technological accumulation in these areas, carbon finance alone may be insufficient to fill the substantial gap in funds and technology [10]. Therefore, the challenges of low-carbon transformation in

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these regions remain significant, requiring more policy support and external cooperation. Hence, Hypothesis 2 is proposed:

H2: Carbon finance's effect on urban low-carbon change varies regionally.

4. Research Design

4.1 Sample Selection and Data Source

This study selects 30 provincial-level administrative regions in China as the research subjects. Considering the availability and characteristics of data, Hong Kong, Macau, and Taiwan are excluded. The sample period is determined to be from 2012 to 2021, based on the availability and consistency of data. The sample data are sourced from the National Bureau of Statistics, China Statistical Yearbook, various provincial statistical yearbooks, the CNRDS China Research Data Service Platform, and the Digital Finance Research Center of Peking University, among others.

4.2 Variable Selection

4.2.1 Dependent Variable

Provincial Low-Carbon Transition Level (LC). For a comprehensive analysis of provincial low-carbon transformation, this paper adopts the new development concepts of innovation, coordination, green, openness, and sharing as principles. Five macro primary indicators are selected: ecological environment, economic growth, technological development, energy utilization, and industrial structure. The choice refers to the research results of Gan et al. (2011) [11], and Yu et al. (2021) [12]. The Analytic Hierarchy Process (AHP) is used to assign weights to the primary indicators, while the Entropy Weight Method is employed for the secondary indicators. The low-carbon transformation score is then obtained through layer-by-layer weighting. As shown in Table 1 below.

Table 1: Provincial Low-Carbon Transformation Scoring System

Primary Indicator	Secondary Indicator	Calculation Method
Ecological Environment	Rate of Harmless Treatment of Domestic Waste	Refer to the "China Statistical Yearbook"
v	Green Coverage Rate in Built-up Areas	Refer to the "China Statistical Yearbook"
	Urban Sewage Treatment Rate	Refer to the EPS database
Economic Growth	Proportion of the Service Industry	The proportion of tertiary industry's added value in GDP
	Per Capita GDP Growth Rate	Current year's per capita GDP compared to last year's GDP
Technological Development	Intensity of Educational Expenditure	Proportion of education expenditure in fiscal expenditure
	Intensity of Science and Technology Expenditure	Proportion of science and technology expenditure in fiscal expenditure
Energy Utilization	Per Capita Carbon Emissions	Carbon emissions compared to the year-end permanent population
	Energy Consumption per Unit of GDP	Carbon emissions compared to GDP
Industrial Structure	Industrial Structure Rationalization Index	Value added of the tertiary industry to value added of the secondary industry
	Industrial Structure Upgrading Index	Value added of the primary industry as a percentage of GDP * 1 + Value added of the secondary industry as a percentage of GDP * 2 + Value added of the tertiary industry as a percentage of GDP * 3

4.2.2 Core Explanatory Variable

Carbon Finance Development Level (CF). This study mainly draws upon the research approaches and indicator systems of Xu et al. (2020) [12], and Zheng et al. (2022) [10] to establish a measurement system for the level of carbon finance development. The indicators are selected and discarded based on the availability and consistency of data within the study period. The final indicator system is as presented in Table 2. The Entropy Weight Method is used to objectively assign weights, resulting in scores for the carbon finance development level of 30 provincial regions in China for the years 2012-2021.

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Table 2: Measurement Indicator System for China's Carbon Finance Development Level

Goal Layer	Benchmark Layer	Indicator Layer	Calculation Method
Carbon Finance Development Level	Financial Factors	Proportion of Added Value in the Financial Sector	The Proportion of Financial Sector's Added Value to GDP
		Intensity of Carbon Emission Loans	The Ratio of Carbon Emissions to Various Loan Balances
	Technological Factors	Research and Development Intensity	Internal Expenditure on Technology R&D as a Percentage of GDP
		Number of Patent Grants	Normalized Number of Patent Grants
	Energy Factors	Elasticity of Energy Consumption	Growth Rate of Energy Consumption Compared to the Same Period GDP Growth Rate

4.2.3 Control Variables

In this study, following the research of Xu et al. (2023) [13], Zhou et al. (2021) [14], and Sun et al. (2020) [15], the following variables are selected as control variables: Digital Finance (DF): The development of the digital economy can, to some extent, replace offline services and promote low-carbon transformation. Government Expenditure (GE): Provincial governments, influenced by administrative assessment indicators, tend to fund projects that can bring rapid economic or social benefits. High-carbon industries often have lower technological thresholds and facility requirements, yielding relatively high returns in a short time, making them more favored by decision-makers than low-carbon projects. Therefore, higher government spending might inhibit provincial low-carbon transformation. Economic Foundation (EB): Different stages of economic development in various regions significantly influence the formulation of urban environmental policies and focus on development goals. Generally, more economically developed areas have higher requirements for low-carbon transformation. Human Capital (HR): Higher education institutions often require a substantial amount of educational facilities. As higher education construction is a key government performance indicator, it tends to receive policy bias, diverting resources that could support low-carbon transformation. Marketization (MA): A higher degree of marketization typically attracts more private capital and investment, driving research and development of low-carbon technologies and solutions, thereby promoting low-carbon transformation. Investment Efficiency (IE): This reflects the state of technology utilization and economic development in progress. Higher investment efficiency usually correlates with higher efficiency in low-carbon transformation. Technology Trade (TT): This indicates the condition of the provincial technology market. A higher level of technology trade often leads to the proliferation of green technologies, thus facilitating low-carbon transformation. As shown in Table 3 below.

Table 3: Selection and Definition of Control Variables

Variable Name	Code	Variable Description
Digital Finance	DF	Logarithm of Peking University's Digital Inclusive Finance Index
Government Fiscal Expenditure	GE	Proportion of General Public Budget Expenditure to GDP
Economic Foundation	EB	Logarithmic Transformation of GDP
Human Capital	HR	Ratio of College Students to Total Population
Marketization	MA	Marketization Index
Investment Efficiency	IE	Incremental Capital Output Ratio = Investment Rate / GDP Growth Rate
Technology Transactions	TT	Ratio of Technology Transaction Volume to Regional GDP

4.3 Model Setting

Environmental issues are characterized by transboundary effects and externalities. Therefore, the low-carbon transformation of a province is influenced not only by local factors but also by relevant factors from neighboring provinces. Considering the potential spatial effects, this study employs the Spatial Durbin Model (SDM) to examine the impact of carbon finance development level on urban low-carbon transformation. The specific model is as follows:

$$LC_{it} = \rho_1 \sum_{i=1}^{n} W_{it} LC_{it} + \beta CF_{it} + \rho_2 \sum_{i=1}^{n} W_{it} CF_{it} + \alpha X_{it} + \rho_3 \sum_{i=1}^{n} W_{it} X_{it} + \varepsilon it + \mu i + \nu i \quad (1)$$

The National Bureau of Statistics of China categorizes the country into Eastern, Central, Western, and Northeastern regions for statistical and research purposes, based on regional characteristics. This paper refers to this geographical division and conducts a regional heterogeneity analysis by dividing the sample into East, Central, West, and Northeast regions, using the aforementioned model.

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5. Empirical Analysis

5.1 Spatial Correlation Test

Global Moran's Index. To study the spatial correlation between the level of low-carbon transformation and the level of carbon finance development in provincial regions, data on these variables from 30 provinces over 10 years (2012-2021) were used. The global Moran's Index was calculated using a spatial geographical distance matrix (calculated based on the inverse of latitude and longitude distances). The results are presented in Table 4. According to Table 4, all the dependent variables' Moran's Indices are positive and significant at the 1% level, and most of the core explanatory variables satisfy the 5% significance level. Overall, there is a positive global spatial correlation between the level of provincial low-carbon transformation and the level of carbon finance development, indicating significant spatial dependency. Both variables exhibit a geographically clustered spatial pattern and positive spatial spillover effects.

Table 4: Global Moran's Index for Provincial Low-Carbon Transformation Level and Carbon Finance Development Level

Year	PL	CF
	Moran's I	Moran's I
2012	0.1142***	0.0054
2013	0.1135***	0.0218
2014	0.1175***	0.0386**
2015	0.1219***	0.0422**
2016	0.1130***	0.0574***
2017	0.1028***	0.0402**
2018	0.0884***	0.0488**
2019	0.0887***	0.0453**
2020	0.0993***	0.0449**
2021	0.1065***	0.0436**

Note: ***, **, and * indicate that the parameter estimates are significant at the 1%, 5%, and 10% significance levels, respectively.

5.2 Construction of Spatial Econometric Model

In this study, a series of tests including LM test, Hausman test, Wald test, and LR test were conducted, and the results were analyzed. The traditional LM tests rejected the null hypothesis, indicating the presence of both spatial lag and spatial error autocorrelation effects. The Spatial Durbin Model (SDM), which considers both these effects, is thus preliminarily determined to be appropriate. The Hausman test results suggest the use of a fixed effects model. The Wald and LR test results indicate that the SDM does not degenerate into a spatial error model or spatial autoregressive model.

The global and regional samples were then analyzed using the SDM, as shown in Table 5. For the overall sample, the regression coefficient of carbon finance development level is 0.0776835 and significant at the 1% level, indicating that the development of carbon finance in a province can effectively enhance the level of provincial low-carbon transformation. The spatial lag coefficient of carbon finance is 0.1508044, with no clear significance. Considering the characteristics of the SDM, the coefficients of the explanatory variables were decomposed, as shown in Table 6. It is observed that the spatial direct and total effects of carbon finance are significantly positive, indicating that the development of carbon finance in a province can effectively promote the low-carbon transformation in that region. The spatial indirect effect of carbon finance has a p-value of 0.109 and does not pass the significance test, suggesting inconsistent indirect effects of carbon finance development across different regions.

In terms of heterogeneity analysis, the analysis of Table 6 reveals that the core explanatory variable, carbon finance, has heterogeneous impacts across different economic regions. Firstly, regarding the local impact of carbon finance development: In China's Central and Eastern regions, where the financial industry is relatively developed and policy requirements for low-carbon transformation are stronger, carbon finance development can effectively curb excessive carbon emissions and greatly promote provincial low-carbon transformation. In Western China, with a relatively backward economic foundation and a primary industry structure, many areas are still dominated by resource extraction, a high-carbon-emitting industry. Achieving low-carbon transformation here requires an overall industrial structure adjustment and upgrade; carbon finance development alone is insufficient [11]. The Northeast region, with its large number of old industrial enterprises and infrastructure, requires significant

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financial and technological investments for upgrading outdated facilities, and carbon finance may not meet this large funding gap [12], thus having an insignificant impact.

Secondly, regarding the impact of carbon finance development on neighboring provinces: In Central and Eastern China, carbon finance development can promote low-carbon transformation in neighboring provinces due to their more diverse economic development models and advanced technology and industrial chain integration capabilities. Businesses in these regions focus more on long-term investments and technological innovation in carbon finance, which more easily leads to low-carbon development in neighboring areas through technology spillover. In contrast, carbon finance development in Western and Northeastern China may hinder low-carbon transformation in neighboring provinces. The Western region, with its relatively harsh natural environment and scarce resources, may prioritize using existing resources and technologies for economic growth and development, thereby occupying resources needed for low-carbon transformation in neighboring provinces. As for the Northeast, despite its abundance of old industrial bases and industrial resources, issues like population outflow, capital scarcity, and rigid industrial structures mean that the province's carbon finance development may occupy resources needed for low-carbon transformation in neighboring provinces, thus impeding their transition [11].

Table 5: Model Regression Results

Sample	Global		Western		Central		Eastern		Northeastern	
VARIABLES	X	WX	X	WX	X	WX	X	WX	X	WX
CF	0.0776835*** (8.32)	0.150804 (1.73)	-.0593458*** (-2.58)	-.453987*** (-3.51)	.4968665*** (9.89)	1.432467*** (7.33)	.0765035*** (5.84)	.1970607*** (3.87)	.1305957 (0.45)	.0724473 (0.09)

Table 6: Direct Effects, Indirect Effects, and Total Effects

		Global	Western	Central	Eastern	Northeastern
Direct Effect	CF	.0779302*** (8.10)	-.0245704 (-1.20)	.3609581*** (6.83)	.0680898*** (5.88)	.1278263 (0.72)
Indirect Effect	CF	.1558099 (1.60)	-.2404415*** (-3.56)	.7301823*** (3.66)	.1451729*** (3.56)	.0254359 (0.04)
Total Effect	CF	.23374** (2.28)	-.2650119*** (-3.56)	1.09114*** (4.38)	.2132628*** (4.42)	.1532623 (0.20)

5.3 Robustness Test

To verify the reliability of the econometric results, this study replaces the spatial distance matrix with a spatial adjacency matrix in the Spatial Durbin Model for regression testing. Furthermore, the original data were subjected to 1% and 5% tailoring treatments, respectively, and Spatial Durbin regression models were constructed using these adjusted datasets. The results confirmed the robustness of the findings through the aforementioned robustness tests.

6. Conclusions and Recommendations

Based on the construction of evaluation indicators for the development level of carbon finance and urban low-carbon transformation, this paper investigates the impact of carbon finance development level on urban low-carbon transformation in 30 provincial-level administrative regions in China from 2012 to 2021. Following the economic zone division of the National Bureau of Statistics, the provinces were divided into four major regions to discuss regional differences in impact. The results show that the development level of carbon finance has a significant positive impact on urban low-carbon transformation. At the same time, the impact of carbon finance development on neighboring provinces varies across different regions, with the development in Western China having a significant negative impact on the low-carbon transformation of adjacent provinces, while in Central and Eastern provinces, it has a significant positive impact. In the Northeast, carbon finance development does not have a significant impact on neighboring regions. The above conclusions play an important role in building an efficient carbon finance development system and promoting the low-carbon transformation process of cities in different regions. Based on these findings, the following recommendations are proposed:

First of all, for enterprises, enterprises in the eastern and central regions should optimize capital allocation, make full use of the advantages of the original financial industry, attract more green investment, and develop low-carbon business. Enterprises in western China should take the initiative to adjust their industrial structure and reduce their dependence on high-carbon industries. At the same time, it will strengthen cooperation with enterprises in the eastern and central regions and introduce

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low-carbon technologies and management experience. For the northeast region, enterprises should improve their own technology research and development capabilities and independently promote low-carbon transformation; Actively cooperate with enterprises in other regions to jointly explore the path of low-carbon transition.

Secondly, for effective low-carbon development, governments need to continuously refine carbon finance policies and increase support for enterprises. In Central and Eastern regions, the focus should be on tax incentives for technology trade and establishing patent incubation centers to foster new low-carbon technologies. In the Western region, the emphasis should be on promoting green banking, providing financial incentives for low-carbon investments, and setting up joint R&D funds to enhance inter-regional cooperation. The Northeast should receive increased fiscal support and investment in carbon finance, particularly through green innovation funds for startups and SMEs, encouraging low-carbon R&D. Additionally, the government should facilitate industrial transformation towards more sustainable sectors and attract skilled professionals in carbon finance and green industries, especially in resource-depleting areas.

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