

Evaluation of the Demonstration and Leading Effects of Green Finance Policies and Promotion Strategies

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TITLE

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Evaluation of the Demonstration and Leading Effects of Green Finance Policies and Promotion Strategies

Abstract: The green finance reform and innovation pilot zone is an important policy tool for promoting the development of green finance. Comprehensively evaluating the demonstration and driving effects of green finance policies constitutes a crucial approach to promoting sustainable development. Based on the panel data of 269 cities in China from 2011 to 2023, the paper adopts fixed-effect models and dual machine learning models to study the demonstration and driving effect of green finance policies on green finance in adjacent non-pilot cities. The study finds that green finance policies have played a demonstration role in the green finance of pilot cities. Meanwhile, green finance policies can drive the development of green finance in adjacent non-pilot cities and have passed robustness tests by replacing the explained variable and the research method. Heterogeneity studies have found that green finance policies in non-resource cities, large cities, economically developed regions, and regions with advanced digital finance have a driving effect on the green finance of adjacent non-pilot cities. Mechanism research has also found that the more pilot cities for green finance policies there are, the more it can stimulate the development of green finance in adjacent non-pilot cities within a province. The institutional pressure brought about by the implementation of environmental quality in the pilot cities of green finance policies themselves has a significant spillover effect on the development of green finance in adjacent non-pilot cities. The environmental quality of green finance policies can stimulate the development of green finance in adjacent non-pilot cities, but this effect can only encourage local governments to engage in environmental protection competitions. To this end, it is crucial to improve the mechanism and system of green finance policies and enhance the quality of green finance policies to provide sufficient impetus for the development of green finance.

Key words: Green finance policy; Adjacent non-pilot; Dual machine learning

1. Literature Review

Against the backdrop of multiple challenges such as global climate change, tightening resource constraints and ecological degradation, green and low-carbon transformation has emerged as a universal strategy for nations worldwide to pursue sustainable development. Since the signing of the Paris Agreement, major economies around the world have successively incorporated green finance into national strategies, promoting the orderly flow of capital into clean energy, green infrastructure and low-carbon technologies. The European Union has established a green finance standard system through the European Green Deal and the Sustainable Finance Classification Scheme. The Inflation Reduction Act of the United States also incentivizes green

investment with a scale of hundreds of billions of dollars. Green finance is progressively evolving into a pivotal nexus at the intersection of global financial governance and climate governance.

With this framework, China, as the world's largest developing country, has also been continuously deepening the construction of its green financial system. In March 2025, China's State Council issued the Guiding Opinions on Advancing the "Five Major Articles" of Finance, explicitly articulating the development principle of "establishing first and then breaking" and emphasizing that green finance serves not only as a pragmatic pathway for financial services to support ecological civilization construction, but also as a critical financial underpinning for promoting high-quality development and realizing harmonious coexistence between humanity and nature. The issuance of this document signifies a pivotal stage in the evolution of China's green finance policy from institutional exploration to systematic integration, while also offering a policy paradigm and practical model with Chinese characteristics for global green finance governance. By the end of 2024, the balance of green loans in China reached 36.6 trillion yuan, with a year-on-year growth rate of 21.7%, accounting for 27.8% of the total loan balance. However, the balance of green bonds was 2.2 trillion yuan, far lower than that of green loans. The issuance scale of green bonds in China has grown from 201.8 billion yuan in 2016 to 683.3 billion yuan in 2024, with an average annual growth rate of 16.5% (see Fig.1).

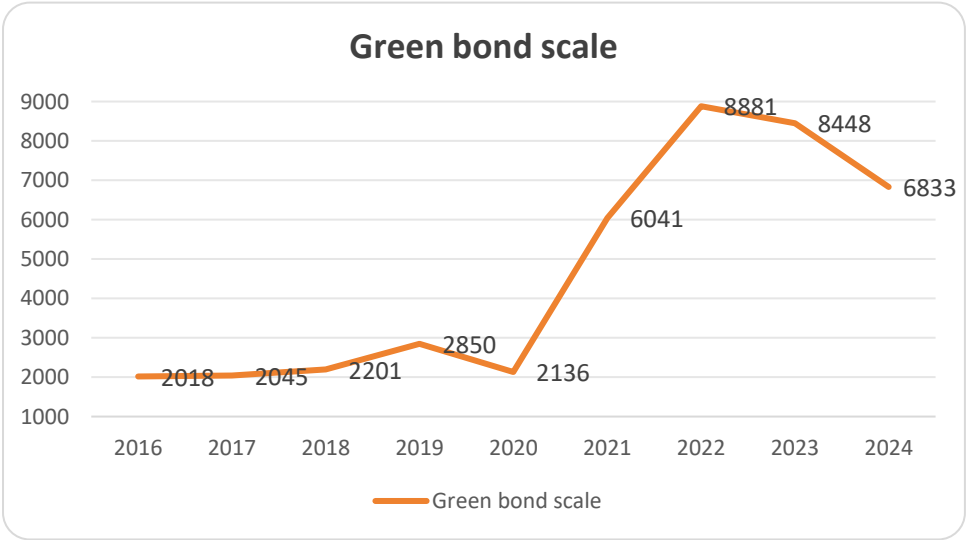


Fig. 1 The issuance scale of green bonds in China from 2016 to 2024

Most of the existing literature constructs a comprehensive index based on green financial products (such as green credit, green bonds, etc.) to measure the development level of green finance (Kong et al., 2021; Yao et al., 2025), which is the mainstream paradigm of current research. However, this paradigm exhibits three key limitations: with respect to the temporal dimension, it

fails to capture the inherent dynamic changes of green finance amid market evolution; regarding the process dimension, it prioritizes the scale of traditional products while overlooking the paradigm shift driven by "technology empowerment" and "product innovation"; and in relation to the outcome dimension, it remains confined to the capital investment phase, failing to effectively link with output-side indicators such as "environmental governance" and the associated benefits it generates.

Due to the absence of these dimensions, the existing indices are difficult to comprehensively and accurately depict the rich connotations of green finance development. This article will expand from the following three aspects.

Firstly, this paper takes 269 prefecture-level and above cities in China as the research objects, comprehensively evaluating the development of green finance from four aspects: scale and market development, product innovation and technological empowerment, environmental regulation and governance, and benefits and achievements, to achieve precise measurement of the development of green finance and form replicable and promotable practical experience. It provides an important reference for the construction of the green financial system in China and even globally.

Secondly, at the level of external effects of green finance policies, current studies on the assessment of green finance pilot policies generally relies on the spatial Durbin model. However, there is still a lack of systematic characterization of its dynamic mechanism of "demonstration-diffusion- feedback", which has led to the long-term "black box" state of policy spillover effects, spatial governance logic and the feasibility of institutional transplantation. Moreover, the heterogeneous spillover effects of policies on pilot and non-pilot cities have not been strictly defined, which may lead to biases in the estimation results of spillover effects.

Thirdly, by adopting a dual machine learning model, the demonstration and driving effect of green finance policies on the development of green finance in adjacent non-pilot cities is studied, and the mechanism role is explored. This is to better evaluate the demonstration and driving effect of green finance policies, form a "competitive upward" model, and promote the high-quality development of green finance.

The rest of the paper is as follows: The **Part 2** is a literature review; The **Part 3** is theoretical analysis; The **Part 4** is the research design; The **Part 5** is the result analysis; The **Part 6** is the extended analysis, which includes heterogeneity analysis and mechanism analysis. The **Part 7** is discussion; The **Part 8** is the conclusion and policy recommendations.

2. Literature Review

2.1. The measure of development of green finance

In the early stage of green finance research, scholars mostly made a preliminary assessment of the development level of green finance from a single or a few dimensions. These early studies mainly focused on a specific area of green finance, such as carbon finance (Li et al., 2019) and green investment (Wang et al., 2020; Shen et al., 2020; Javeed et al., 2024), green bonds (Meo and

Karim, 2022; Naifar, 2025; Sharma and Sharma, 2025) , green credit (Shahzad et al., 2024; Xu, 2025), climate mitigation finance (Khan et al., 2022), green finance (Wan et al., 2022; Arshian et al., 2022), etc. Although these single-dimensional indicators can reflect the development status of specific fields to a certain extent, they often fail to comprehensively and systematically depict the overall development level and comprehensive benefits of green finance. Some scholars have attempted to construct a more comprehensive evaluation system to assess the development of green finance more comprehensively by integrating multiple core dimensions (Akomea-Frimpong et al., 2022). For instance, the research by Kong et al. (2021) and Yao et al. (2025) comprehensively considered multiple key market segments such as green securities, green insurance, green investment, and carbon finance, aiming to reflect the overall coordinated development status of the green financial system through the integration of multiple indicators. Furthermore, the research perspective continues to broaden and begins.

2.2. The impact and role of green finance development.

In the early stage of green finance research, scholars mainly focused on exploring the influence of its core components and direct driving forces. With the continuous expansion and deepening of research perspectives, the academic community has begun to examine green finance within a more complex and diverse external environment and cross-disciplinary system, significantly enriching the research dimensions. Specifically, recent studies have extensively focused on the influence of economic and resource-based factors, such as the supporting role of natural resource rents (Liang et al., 2024) , as well as the pulling effects of renewable energy investment and green public resources (Dong et al., 2023) . At the policy and institutional level, climate policy uncertainty (Wu and Liu, 2023) , institutional quality (Xu et al., 2023) , environmental regulation (Xu et al., 2022; Mamun et al., 2025), the effectiveness of public expenditure (Zhang et al., 2021) has become the focus of research. Meanwhile, the dimensions of technology and innovation have received high attention, relevant research involves digital finance (Javeed et al., 2024) , technology finance (Mirza et al., 2023; Wan et al., 2023), and the empowerment of blockchain technology in advancing green finance development (Zhang et al., 2018; Kalaiarasi and Kirubahari, 2023). The research perspectives also extend to the social culture and behavioral levels, including leadership and business culture (Torvanger et al., 2021; Dell 'Atti et al., 2022) , women's political empowerment (Mamun et al., 2024), and social trust (Susan et al., 2024).

2.3. Policy research on green finance

In the initial stage of the implementation of the green finance reform and innovation pilot zone, scholars' research focused on the phased evolution and development trends during the policy implementation process. As research advances, scholars have conducted in-depth analysis and evaluation of the role of green financial policies in promoting green development, enhancing environmental benefits, and generating economic effects. In terms of domain development, green

financial policies can enhance the level of green productivity (Lee and Lee, 2022) and drive urban green growth (Zhao et al., 2025) and green technological innovation (Jin and Huang, 2025) . They also promote urban green total factor productivity (Liu et al., 2024) and inclusive green growth (Xu et al., 2025) , among other outcomes. Regarding environmental benefits, green finance policies contribute to carbon reduction (Zhu et al., 2025), reduce industrial soot, sulfur dioxide, and wastewater emissions (Muganyi et al., 2021; Lin and Chi, 2025), and enhance the synergistic effects of corporate pollution and carbon reduction (Fan et al., 2025).

2.4. Research on the demonstration of green finance policies driving the development of green finance

First, policy guidance and resource reallocation. The core role of green finance policy demonstration lies in guiding the allocation of financial resources toward green projects. Research shows that pilot zone policies can significantly improve urban green development efficiency (Yao et al., 2025). The policy has effectively lowered the financing threshold and cost of green projects by building a project library, launching innovative loan products and establishing a special green finance connection mechanism (Wang et al., 2020) .

Second, market system and capacity building. Policy demonstrations promote the formation of a multi-level green financial product system and innovative models. For instance, through a series of measures such as establishing a comprehensive green finance service platform, developing green bonds, and setting up industrial funds, the convenience and professionalism of green financing have been effectively enhanced (Wan et al., 2022) . Financial institutions themselves are also being pushed to establish green specialized agencies to enhance their professional service capabilities (Kong et al., 2021) .

Third, spatial spillover and regional coordination. The impact of green finance policies is not limited to the policy area; it can also drive the development of surrounding regions (Xu et al., 2023). However, this spillover effect may also have a negative impact due to resource agglomeration. For example, it may lead to the concentration of capital and green enterprises in the policy pilot areas, exerting a certain crowding-out effect on the surrounding areas (Wu and Liu, 2023).

2.5. The methods of green finance

Scholars selectively adopt econometric models in a targeted manner based on specific research questions and data characteristics to precisely identify the policy effects, mechanisms of action, and development patterns of green finance. First, in the field of policy evaluation, the difference-in-differences (DID) method has become the mainstream approach for assessing the effectiveness of green finance policies due to its advantage in identifying the net effect of policies under the "quasi-natural experiment" setting (Xin et al., 2022; Zhao et al., 2025) . When research involves dynamic adjustment processes, the dynamic panel GMM model can effectively address the endogeneity issue. Sun et al. (2024) utilized this method to reveal the dynamic relationship

between green finance development and economic growth. Second, in terms of mechanism research, the mediating effect (Zhao et al., 2023) and the moderating effect model (Yin et al., 2023) constitute the core analytical framework. Zhang et al. (2021) confirmed that public expenditure promotes green economic growth through green finance. Kong et al. (2021) found that green finance significantly moderates the impact of high-speed rail opening on urban green productivity. The threshold effect model reveals that when the economic development level crosses a certain threshold value, the marginal effect of green finance will undergo structural changes (Zhang et al., 2025) . Third, the spatial spillover effect model breaks through the assumption of regional independence and confirms that green finance has a significant positive spatial spillover effect on the surrounding areas (Su et al., 2025). In addition, quantile regression models are sufficient to analyze the heterogeneous impact of green finance on different conditional distributions (Naeem et al., 2021; Sinha et al., 2021). Finally, a few scholars began to introduce dual machine learning models into this field (Wang et al., 2025) . This method has obvious advantages in dealing with high-dimensional control variables and complex function forms, and can identify causal effects from observed data in a more flexible and robust way, representing the latest development direction of causal inference research in green finance.

In conclusion, scholars have examined green finance policies and development from multiple perspectives, establishing a robust theoretical foundation for this study. However, gaps remain in the research on green finance development.

This article aims to fill these gaps by exploring the potential spillover effects of green finance reform and innovation pilot zones between pilot cities and adjacent non-pilot cities, as well as their role in driving the development of green finance in adjacent non-pilot cities.

This study focuses on the development effects of green finance, encompassing four dimensions: scale and market development, product innovation and technological empowerment, environmental regulation and governance, and benefits and achievements. Treating green finance pilot and non-pilot policies as a quasi-natural experiment, this paper employs a double machine learning model to analyze their impact on green finance development, empirically tests the existence of demonstration effects and demonstration-driven mechanisms, and integrates the analysis of heterogeneous policy impacts and mechanism effects, thereby contributing to the existing literature.

3. Theoretical analysis

The institutional theory posits that organizations can effectively obtain the necessary legitimacy basis for gaining the recognition of stakeholders through their responses to the external institutional framework. This legitimacy is constructed through the dynamic adaptation of formal and informal rule systems within the institutional environment-these rules have constraints or incentives on social behavior and form specific institutional structural systems. This system consists of three interacting dimensions: the cultural cognition dimension is manifested as the

implicit consensus at the value concept level, the social norms dimension represents the explicit scale of behavioral standards, and the regulation dimension forms a mandatory constraint framework through policies and regulations. Organizations need to establish a dynamic balance among these complex elements through continuous institutional embedding and strategic adaptation (Rath et al., 2025) . In the field of public governance, this institutional adjustment will promote the formation of institutionalized behavioral patterns among government organizations. When specific institutional arrangements mature, there will be mandatory isomorphic pressure requiring other organizations to follow the established norms, and there will also be a demonstration-driven effect that triggers imitative isomorphism (DiMaggio and Powell, 1983) , ultimately leading to the phenomenon of institutional convergence. Based on this theoretical framework, this study focuses on the green finance innovation reform pilot zone, by constructing a dual comparison dimension of pilot cities and adjacent non-pilot cities, systematically analyzing the internal mechanism of institutional innovation driving green finance development, particularly paying attention to how policy pilot programs generate demonstration-driven effects through institutional reconstruction, and how non-pilot cities adjacent geographically respond to changes in the institutional environment, thereby revealing the dynamic mechanism of regional green finance collaborative development.

3.1. The Mechanism of the Impact of Green Finance Policies on the Development of Green Finance in Pilot Cities

For pilot cities implementing green finance policies, their exemplary status as "initiators of the system" can not only create institutional competitive advantages but also imply the risk of path dependence. This seemingly contradictory institutional effect stems from the interaction mechanism between the "advantage of the pioneer" and the "institutional inertia", and its deep mechanism is reflected in three dimensions. First, the institutional certification effect: The status of pilot cities implementing green finance policies serves as a credit endorsement from the central government, thereby generating a resource agglomeration effect (Deeds et al., 2004), which prompts financial tools such as green loans and green bonds to achieve capital diversion through differentiated interest rate mechanisms and special risk compensation funds. Second, the policy depression effect. The institutional arrangements of the central government's tax incentives and preferential land allocation essentially construct a policy arbitrage space, which can guide the directional concentration of market factors. Although this institutional potential can accelerate the vertical integration and horizontal expansion of the green industrial chain, it may also trigger "institutional dividend dependence syndrome"-when innovation benefits mainly come from policies rather than market mechanisms, it will weaken the marginal effect of institutional innovation. Third, the structural imbalance of institutional incentives. In the current pilot assessment framework, there is a deviation in the assessment weights between policy implementation and institutional innovation, resulting in a deviation between institutional

commitment and substantive performance (Irfan et al., 1990). On the one hand, pilot cities can obtain the reputation effect and the substitute role of policy tilt by obtaining the pioneer label, thereby compensating to some extent for the pursuit of economic benefits. On the other hand, due to the imperfect assessment system and information disclosure, pilot cities may focus more on obtaining policy support and reputation enhancement, obtaining green certification premiums through institutional arbitrage rather than substantially improving environmental performance.

During the implementation of green finance policies, the current assessment system still needs further improvement. Due to the incomplete evaluation system for green finance development and the lack of unified and standardized information disclosure standards at the city level, it is difficult to accurately assess the implementation effect of green finance policies, which may lead to misunderstandings or doubts from external stakeholders regarding the green finance activities of pilot cities. However, since the exit mechanism for green finance policies has not yet been clearly established, pilot cities will not suffer excessive negative impacts regardless of their implementation effectiveness. Moreover, the implementation of green finance policies provides pilot cities with a new performance assessment method. This assessment method is centered on the green development goals, driven by product innovation and technological empowerment, and measures economic benefits as the key evaluation criteria. It no longer focuses solely on traditional economic growth indicators but shifts the focus to environmental protection and resource conservation, the value exploration and utilization of products, and the transformation and application of results. This enables pilot cities to effectively alleviate the pressure brought by traditional performance assessment methods during the promotion of green finance development. Finally, pilot cities can use this opportunity to showcase their positive achievements in green industries and other fields, thereby enhancing the overall image of the city, strengthening the legitimacy, reputation, and influence of the pilot policies in the field of green finance development, and reducing doubts and interference from external stakeholders. On this basis, green finance policies can provide financial support, optimize resource allocation, reduce financing costs, promote innovative transformation finance, and other methods to attract more investment in clean energy, energy conservation and environmental protection, etc., thereby effectively promoting the development of green finance. Therefore, this paper proposes Hypothesis 1:

Hypothesis H1: Green finance policies can have a demonstration effect on the development of green finance in pilot cities.

3.2. The Mechanism of the Impact of Green Finance Policies on the Development of Green Finance in Adjacent Non-Pilot Cities

Adjacent non-pilot cities are under the pressure of the pioneer system in the pilot areas (Tian et al., 2021). This pressure may drive their green finance innovation process. By developing new green credit and bond tools, non-pilot cities can meet the investment needs of emerging industries and expand the green financial service network, thereby enhancing regional development

momentum.

Firstly, the pioneer label indicates that the pilot cities have achieved remarkable results in environmental governance, green financial product innovation, and market development. This sends out positive signals of green and environmental development to the outside world, exerting significant institutional pressure on adjacent non-pilot cities, especially resource competition pressure. Due to the lack of policy qualifications, non-pilot cities are often regarded as having institutional disadvantages in green project approval, industrial investment attraction, etc. To regain competitive advantages, adjacent non-pilot cities usually learn from the pilot cities and adopt a competitive catch-up strategy. Through regional coordination mechanisms, they optimize industrial layouts, strengthen policy supply efficiency, accelerate the green transformation process of traditional industries, product innovation and transformation and application, promote green finance development, and achieve sustained economic development.

Secondly, the governance outcomes of the pilot cities have become an important reference for the performance evaluation of non-pilot areas. Cities adjacent to non-pilot areas may face stricter environmental supervision and higher pollution control costs due to lower environmental legitimacy, thereby increasing their pressure for political performance assessment. This, in turn, forces them to seek breakthroughs through green financial innovation. Such innovation covers dimensions such as expanding market scale, empowering technological research and development, and strengthening environmental regulations. It can not only cultivate new growth poles but also enhance sustainable development capabilities. Therefore, the institutional pressure in the pilot cities has essentially formed a push mechanism, driving non-pilot cities to build a "policy improvement--product innovation--regional collaboration" composite development path, improving the level of green finance development, and achieving sustainable development. Therefore, this paper proposes Hypothesis 2:

Hypothesis H2: Green financial policies can drive the development of green finance in adjacent non-pilot cities.

4. Study design

4.1. Measurement methods for the development level of green finance

To obtain the final level of green finance development, this paper adopts the entropy method to assign weights to the indicators. Specific practices are as follows. First of all, according to the formulas (1)-(2), standardize each indicator to ensure the comparability among them.

$$X_{it} = \frac{X_{it} - \min(X_i)}{\max(X_i) - \min(X_i)} \quad (1)$$

$$X_{it} = \frac{\max(X_i) - X_{it}}{\max(X_i) - \min(X_i)} \quad (2)$$

Secondly, calculate the proportion of the index i in the t year. The calculation formula is as follows:

$$\omega_{it} = \frac{x_{it}}{\sum_{i=1}^m x_{it}} \quad (3)$$

Among them, m is the year of investigation. On this basis, calculate the information entropy of the indicator, and the calculation formula is:

$$e_i = \frac{-1}{\ln m} \sum_{i=1}^m \omega_{it} \ln \omega_{it} \quad (4)$$

Calculate the redundancy of information entropy

$$d_i = 1 - e_i \quad (5)$$

The indicator i , with weights of:

$$W_i = \frac{d_i}{\sum_{i=1}^m d_i} \quad (6)$$

The indicators and their weights are weighted to ultimately obtain the development level of green finance.

4.2. Model Construction

To test the above research hypotheses, this paper identifies the impact of green finance policies on the development of green finance in pilot cities (adjacent to non-pilot cities) based on the Double Machine Learning method. Drawing on the method of Wang et al. (2025), a dual machine learning model is constructed as follows:

$$gfi_{it+1} = \alpha_1 x_{it} + g(control_{it}) + u_{it} \quad (7)$$

$$E(u_{it}|pilotdid_{it}, control_{it}) = 0 \quad (8)$$

In the formula, the subscripts i and t respectively represent regions and years; gfi_{it+1} represents the level of green financial development; x_{it} represents green financial policy pilot cities and green financial policy adjacent non-pilot cities; $control_{it}$ represents the control variables affecting green financial development; u_{it} represents the error term.

If the formulas (7) and (8) are directly estimated, the estimated value of $\hat{\alpha}$ will be biased. The reason for this is that in high-dimensional or complex model settings, machine learning models need to introduce regularization terms to reduce dimensionality. Although this avoids the excessive variance of the estimator, it also brings about regularized bias in the function, making it difficult for $\hat{\alpha}$ to converge to α_1 . To solve this problem, the following auxiliary regression is constructed:

$$x_{it} = m(control_{it}) + v_{it} \quad (9)$$

$$E(v_{it}|control_{it}) = 0 \quad (10)$$

In the formula, $m(control_{it})$ represents the regression function of the control variable on the high-dimensional control variable, and its specific form needs to be estimated based on machine learning algorithms. The specific method is as follows: The first step is to estimate $\hat{m}(control_{it})$ using a machine learning model, obtaining the estimator $\hat{m}(control_{it})$, and then calculate the estimator of the residual term $\hat{v}_{it} = x_{it} - \hat{m}(control_{it})$; The second step is to expand the estimation of $\hat{v}_{it}$ as the instrumental variable of gfi_{it+1} ; The third step is to continue

to estimate the estimator $\hat{g}(control_{it})$ of the function $g(control_{it})$ using the machine learning algorithm, and obtain the unbiased estimate.

$$\hat{\alpha}_1 = (\frac{1}{n} \sum_{i \in I, t \in T} \hat{v}_{it} x_{it})^{-1} \frac{1}{n} \sum_{i \in I, t \in T} \hat{v}_{it} (gfi_{it+1} - \hat{g}(control_{it})) \quad (11)$$

4.3. Variable Selection and Data Explanation

4.3.1. Dependent variables

The development of green finance, as a cutting-edge form of the sustainable financial system, is characterized by emphasizing and achieving the intrinsic unity of environmental goals and economic benefits. This development model not only pursues economic growth, but also pays more attention to the integrated coordination of ecological environment protection, efficient resource utilization and social equity and well-being. By integrating innovative financial tools, scientific environmental risk assessment and the core concept of sustainable development, green finance is committed to building a modern financial system featuring efficient resource allocation, controllable environmental risks and sustainable development models, in order to promote the long-term stable development of the economy, society and environment in a coordinated manner. To this end, drawing on existing research and the methodological frameworks of Akomea-Frimpong et al. (2022) and Xue and Feng (2024), this paper constructs four primary indicators: scale and market development, product innovation and technological empowerment, environmental regulation and governance, and benefits and achievements. These primary indicators are further refined into 18 tertiary indicators (see Table 1), and the entropy method was employed to conduct a comprehensive evaluation of urban green finance development (*gfi*).

Table 1

Evaluation Index System of Green Finance

Primary Indicators	Secondary Indicators	Third-level Indicators	Attributes
Scale and Market Development	Scale Development	Green Credit Total(Billion Yuan)	+
		Green Bond Issuance Total (Billion Yuan)	+
		Environmental Pollution Liability Insurance Revenue (Billion Yuan)	+
	Market Development	Carbon Trading, Energy Use Rights Trading, Pollution Rights Trading (Billion Yuan)	+
		Agricultural Insurance Premium Revenue (Billion Yuan)	+
		Carbon Emission/Financial Loan Balance (Tons/Million Yuan)	+
Product innovation and technological empowerment	Product Innovation	Green Fund Total Market Value/All Fund Total Market Value(-)	+
		Green Patent (Hundred Pieces)	+
	Technology Empowerment	Green Utility Model Patent (Hundred Pieces)	+
		Environmental Pollution Control Investment/GDP(-)	+
Environmental regulation and governance	Environmental Regulation	Fiscal environmental protection expenditure/general fiscal budget expenditure(-)	+
		The centralized treatment rate of sewage treatment	+

Benefits and Outcomes	Governance	plants(%)	
		Industrial Solid Waste Comprehensive Utilization Rate(%)	+
	Social Benefit	Green Finance Public Participation Degree	+
		Per Capita GDP (Yuan)	+
	Economic Benefit	Financial Industry Added Value of Prefecture-level Cities (Billion Yuan)	+
	Environmental Benefit	Increase in Carbon Emissions (Tons)	-
		Energy Consumption Growth Rate per Unit GDP	-

4.3.2. Explanatory variables

Green financial policies are measured by the pilot cities of green financial innovation and reform pilot programs ($pilotdid_{it}$), and $pilotdid_{it} = treat_{it} * post_{it}$, where $treat_{it}$ indicates whether a certain prefecture-level or higher city has implemented the green financial pilot policy. If a certain prefecture-level or higher city has implemented the green financial pilot policy, then $treat_{it} = 1$; otherwise, it is 0. And $post_{it}$ represents the implementation time of the policy. If $pilotdid_{it} = 1$, it indicates that city i belongs to the "green financial innovation and reform pilot program" in year t ; if $pilotdid_{it} = 0$, it indicates that city i does not belong to the "green financial innovation and reform pilot program" in year t . $peerdid_{it}$ represents green financial policies for neighboring non-pilot cities. If the neighboring city i of a certain city belongs to the green financial innovation and reform pilot program in year t , then $peerdid_{it} = 1$; otherwise, it is $peerdid_{it} = 0$.

4.3.3. Control variables

In order to avoid missing important variables, this paper controls for the macro-level factors that affect green finance. (1) The industrial structure ($indu$) is measured by the proportion of the added value of the secondary industry in the regional GDP. (2) To quantify fiscal expenditure (fis), we adopt the ratio of total fiscal expenditure to GDP, a metric widely used to gauge the government's fiscal intervention intensity in the economy. (3) The level of financial development (fin) is measured by the proportion of the sum of financial deposits and loans to GDP. (4) The level of open development is proxied by the proportion of the total volume of imports and exports to the regional GDP. (5) Human capital (edu) is measured by the ratio of the number of people with college degrees or above to the total population. (6) Population density is calculated by the ratio of the total population to the administrative area of a region.

4.3.4. Data sources

Considering the availability and validity of the data, this paper constructed panel data of 269 cities in China from 2011 to 2023. The city samples excluded cities in Xizang, Hong Kong, Macao and Taiwan, as well as cities with more missing data such as Chaohu, Laiwu, Bijie and Tongren. The average value was used to fill in the individual missing data, totaling 3,479 samples. All data are derived from the China Urban Statistical Yearbook, Statistical Yearbook of Listed Companies, China Energy Statistical Yearbook, China Environmental Statistical Yearbook, China Science and

Technology Statistical Yearbook, China Financial Yearbook, and statistical yearbooks of various provinces (municipalities). The descriptive statistics of the main variables are shown in Table 2.

Table 2
Descriptive Statistics of Main Variables

Variable	Abbreviation	Obs	Mean	Std. Dev.	Median	Min	Max
Green Finance Development Level	<i>gfi</i>	3497	0.205	0.046	0.198	0.129	0.671
Green Finance Policy	<i>poiltidid</i>	3497	0.016	0.126	0.000	0.000	1.000
Industrial Structure	<i>indu</i>	3497	0.445	0.109	0.451	0.043	0.821
Fiscal Expenditure Level	<i>fis</i>	3497	0.198	0.093	0.175	0.044	0.741
The level of financial development	<i>fin</i>	3497	1.113	0.673	0.933	0.132	12.817
The level of financial development	<i>open</i>	3497	0.182	0.301	0.078	0.000	6.021
Human Capital	<i>edu</i>	3497	0.021	0.026	0.011	0.000	0.266
Population density	<i>density</i>	3497	4.579	3.618	3.799	0.051	34.301

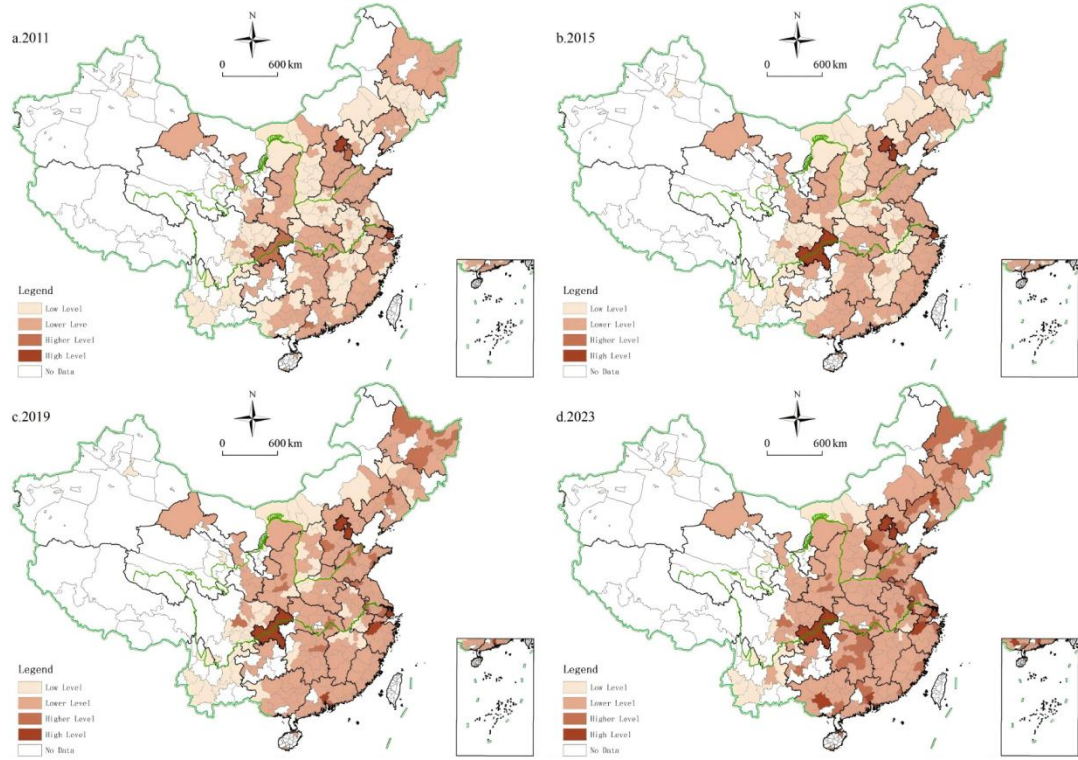
5. Results analysis

5.1. The spatio-temporal evolution of the development level of green finance

To deeply analyze the spatio-temporal evolution characteristics of the development level of green finance in Chinese cities, this paper selects four time points of 2011, 2015, 2019 and 2023, and uses ArcGIS software to divide the development of green finance into four levels: low level, relatively low level, relatively high level and high level for visualization (**Fig. 2**).

In 2011, the overall development level of green finance in China was relatively low, with the proportion of samples at a low level and a relatively low level being approximately 42.01% and 54.65% respectively. In 2015, the proportion of samples in China where the development of green finance was at a low level and a relatively low level was approximately 37.17% and 59.11% respectively, and the number of cities in the low-level area decreased. There are six cities with green finance development at a relatively high level or above, among which only four are at a high level (Beijing, Tianjin, Shanghai and Chongqing). In 2019, the proportion of samples in China where the development of urban green finance was at a low level and a relatively low level was approximately 21.56% and 66.17% respectively, and the number of cities in the low-level area decreased significantly. The sample proportion of green finance development at a relatively high level or above is 9.67%. Among them, the number of high-level regions has increased by 3 cities, mainly distributed in developed areas and large cities, showing a scattered feature. In 2023, the proportion of China's green finance development at a low level and the sum of samples at a

relatively low level was 78.07%, which decreased compared with 2011, 2015 and 2019. Overall, it achieved a certain degree of development. The regions with relatively high and high-level green finance development have shown a certain trend of contraction and agglomeration, and this trend is constantly strengthening. A small number of relatively high and high-level cities have regressed to relatively low-level cities (such as Dongguan and Dongying), and these cities are located in non-central areas. In contrast, most provincial capital cities and central cities have always maintained a relatively high and high-level level.



Note: This is made based on the standard map with review number GS(2023)2767 downloaded from the standard map service website of the Ministry of Natural Resources. The boundaries of the base map have not been modified.

Fig. 2 China urban spatial distribution of green financial development level evolution

5.2. Stable trend test

Before conducting empirical research, it is necessary to first determine whether the trends of the treatment group and the control group remain consistent before the policy implementation and do not show systematic differences over time. Therefore, this paper draws on the research method of McGavock (2021), and adopts the event analysis method to test the parallel trend hypothesis and analyze the dynamic effects of policies. The specific model is as follows:

$$gfi_{it} = \beta_0 + \sum_{k=-4}^{k=2} \beta_k D_{it}^k + \gamma_1 control + \eta_i + \tau_t + \varepsilon_{it} \quad (11)$$

where D_{it}^k is a dummy variable representing the implementation of the green finance policy. Assuming that the year when a city starts implementing the green finance pilot program is y_i , if $t - y_i = k$, then $D_{it}^k = 1$, otherwise it is 0. Here, $k = -4, -3, \dots, 2$. This paper uniformly classifies

the previous 4 periods before the policy shock and the subsequent 2 periods after it as -4 and 2 respectively, to avoid multicollinearity, the -1 period is deleted here. By comparing the economic and statistical significance of parameter β_k in Eq. (11), the time variation of the effect of the green finance policy can be tested. The control variables are consistent with the baseline model Eq. (1).

The regression results are shown in **Fig. 3**. The coefficients before the implementation of the green finance policy did not pass the significance test, indicating that before the implementation of the green finance policy, the changing trends of green finance development in the treatment group and the control group met the parallel trend assumption. Furthermore, the policy effect of green finance was significantly positive in the year of its implementation and thereafter, indicating that the policy was conducive to the development of green finance in the year of its implementation and thereafter. Therefore, it is assumed that H1 has been preliminarily verified.

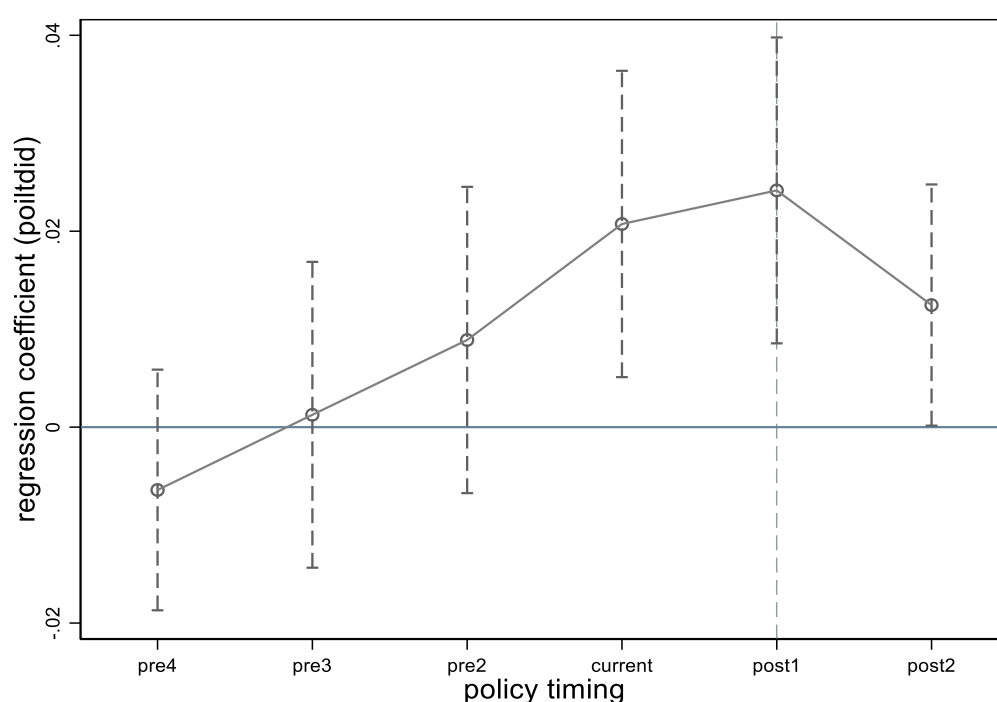


Fig.3. Parallel trend test

5.3. Benchmark regression results

The selection of pilot cities follows the principle of open application and selective selection, and the selection process has an endogenous characteristic. However, it should be emphasized that whether the applicant entity participates in the pilot before the approval of the experimental zone has no correlation with adjacent non-pilot cities. Therefore, under the condition of exogenous policy shocks, the impact of green finance policies in the framework of this study on adjacent non-pilot cities has strict exogenous attributes. The premise for the spillover effect of green finance policies is that the pilot cities significantly improve their green finance development levels through policy practice, and then promote the coordinated development of adjacent non-pilot

cities through the experience transmission mechanism. This study evaluates policy effects using a dual machine learning model. The training set and test set are divided in a 1:4 ratio. The random forest algorithm is used to predict and solve the main regression and auxiliary regression models. The regression results are shown in Table 3. Model (1) controls the first-order terms of control variables, regional fixed effects, etc. in the full sample range. It can be found that the coefficient of green finance policies on the green finance development of pilot cities is 0.020, and it is significant at the 1% level. Based on Model (1)-(3), Model (4) controls the first-order and second-order terms of variables, city fixed effects, and time fixed effects. It can be found that the coefficient of green finance policies on the green finance development of pilot cities is still significantly positive, indicating that green finance policies can enhance the green finance development level of pilot cities. Therefore, consistent with the theoretical expectation, Hypothesis H1 is further verified.

Table 3

The impact of green finance policies on green finance in pilot cities

Variable	(1) <i>gfi</i>	(2) <i>gfi</i>	(3) <i>gfi</i>	(4) <i>gfi</i>
<i>poiltdid</i>	0.020*** (3.861)	0.020*** (3.855)	0.020*** (4.028)	0.021*** (4.041)
cons	0.000 (0.355)	0.000 (0.592)	0.000 (0.339)	0.000 (0.570)
First-order control variables	Y	Y	Y	Y
Second-order control variables	N	N	Y	Y
Time fixation effect	N	Y	N	Y
Regional fixed effect	Y	Y	Y	Y
Sample size	3497	3497	3497	3497

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

According to the previous analysis, green finance policies may also drive the development of green finance in adjacent non-pilot cities. This paper conducts empirical tests, and the results are shown in Table 4. Model (1) controlled the primary term of the control variable and the regional fixed effect within the entire sample interval. It can be found that the coefficient of green finance policies on the development of green finance in adjacent non-pilot cities is 0.005, and it is significant at the 10% level. Based on models (1) to (3), Model (4) controls for the primary and secondary terms of variables, urban fixed effects, and time fixed effects. It can be found that the coefficient of green finance policies on the development of green finance in adjacent non-pilot cities remains significantly positive, indicating that green finance policies can produce a demonstration and driving effect on the development of green finance in adjacent non-pilot cities. Compared with non-adjacent non-pilot cities, green finance policies have increased the development of green finance in adjacent non-pilot cities by 0.5%, indicating that green finance policies are conducive to the development of green finance in adjacent non-pilot cities. This

reflects that green finance policies will bring "green" institutional pressure and drive the improvement of green finance development in adjacent non-pilot cities. Therefore, consistent with theoretical expectations, hypothesis H2 has been verified.

Table 4

The impact of green finance policies on green finance development in adjacent non-pilot cities

Variables	(1) <i>gfi</i>	(2) <i>gfi</i>	(3) <i>gfi</i>	(4) <i>gfi</i>
<i>peerdid</i>	0.005* (1.724)	0.009*** (2.829)	0.009*** (2.970)	0.005* (1.715)
cons	0.000 (0.582)	0.000 (0.498)	0.000 (0.470)	0.000 (0.496)
First-order control variables	Y	Y	Y	Y
Second-order control variables	N	N	Y	Y
Time fixation effect	N	N	N	Y
Regional fixed effect	Y	Y	Y	Y
Sample size	3380	3380	3380	3380

5.4. Robustness test

Firstly, replace explanatory variables. In this paper, the adjacent non-pilot cities of green finance policies are replaced with non-pilot cities of green finance policies for regression, as shown in Model (1) of Table 5. The results show that green finance policies have a significant promoting effect on the development of green finance in non-pilot cities, which proves the robustness of the empirical results of this paper.

Secondly, end processing. Correct the outliers of all variables, tail the maximum and minimum 1% samples of all variables, and then regress, as shown in Model (2) of Table 5. Green finance policies still have a significant promoting effect on the development of green finance in adjacent non-pilot cities, which is consistent with the direction of the benchmark regression results mentioned above.

Thirdly, excluding special samples. Considering the political status and special resource endowment conditions of municipalities directly under the Central Government, there may be significant differences from other prefecture-level cities, which may lead to biases in the regression results. Therefore, this paper excludes municipalities directly under the Central Government and then conducts regression, as shown in Model (3) of Table 5. After eliminating special samples, green finance policies still have a significant promoting effect on the development of green finance in adjacent non-pilot cities, which proves the robustness of the empirical results of this paper.

Fourthly, the data is centralized processing. To alleviate the bias caused by potential

multicollinearity problems, this paper centers all control variables and then conducts regression, as shown in Model (4) of Table 5. Green finance policies still have a significant promoting effect on the development of green finance in adjacent non-pilot cities, which also proves the robustness of the empirical results of this paper.

Fifthly, considering interaction area - time fixed effects. Since cities in the same region often share similarities in terms of location characteristics, historical culture, etc., this paper adds the regionally temporal interaction fixed effect on the basis of the benchmark regression. The regression results are shown in Model (5) of Table 5. Green finance policies still have a significant promoting effect on the development of green finance in adjacent non-pilot cities, and still support the conclusion of the previous text.

Table 5

Results of Robustness Tests

Variable	(1)Replaced the Dependent Variable	(2)Truncated Handling	(3)Excluding Special Administrative Regions	(4)Centralization Processing	(5)Interaction Terms of Region and Time
<i>peerdid</i>	0.019*** (5.517)	0.006* (1.936)	0.008*** (2.726)	0.005* (1.689)	0.005* (1.761)
cons	0.000 (1.123)	0.000 (0.416)	0.000 (0.600)	0.000 (0.505)	0.000 (0.672)
First-order control variables	Y	Y	Y	Y	Y
Second-order control variables	Y	Y	Y	Y	Y
Time fixation effect	Y	Y	Y	Y	Y
Regional fixed effect	Y	Y	Y	Y	Y
Fixed Interaction Terms of Region and Time	N	N	N	N	Y
Sample size	3380	3380	3341	3380	3380

6. Extended Analysis

6.1. Heterogeneity analysis

The previous analysis examined the impact of green finance policies on the green finance of adjacent non-pilot cities. However, due to the diversity of resource distribution and development stages, the development of green finance shows significant heterogeneity. Therefore, the demonstration and driving effects of green finance policies on the green finance of adjacent non-pilot cities may vary. Thus, it is necessary to further explore these differences.

6.1.1. City Types

This paper uses the "New Tiered List of Chinese Cities" published by the New First-tier City Research Institute to divide the research samples into two sub-samples: large cities and medium and small cities [For the detailed classification criteria, please refer to the "City Commercial Appeal Ranking" released by the New First-tier City Research Institute.]. The regression results are shown in models (1)-(2) of Table 6. The results indicate that the coefficient of the impact of green finance policies on the green finance development of adjacent non-pilot cities in large cities is positive and passes the significance test at the 1% level, but the impact on medium and small cities is not significant. Second, resource-based cities. As a group of cities that rely on the development and primary processing of mineral resources as their economic pillar, resource-based cities are characterized by large reserves of fossil energy (Fan et al., 2021) , but there is still room for improvement in energy efficiency. Based on the list provided by the "National Sustainable Development Plan for Resource-based Cities", this paper clearly divides the entire sample of cities into two categories: resource-based and non-resource-based, as shown in models (3)-(4) of Table 8. Specifically, the coefficients of the impact of green finance policies on the green finance development of adjacent non-pilot cities in non-resource-based and resource-based cities are 0.009 and 0.007, respectively. However, the coefficient for resource-based cities does not pass the significance test, indicating that green finance policies have a positive effect on the green finance development of adjacent non-pilot cities in non-resource-based cities.

Table 6
Results of Heterogeneity Test 1

Variables	(1)Large cities	(2)Small-medium cities	(3)Non-resource city	(4)resources-based city
<i>peerdid</i>	0.015*** (3.294)	-0.005 (-1.352)	0.009** (2.195)	0.007 (1.201)
cons	0.001 (0.934)	0.000 (0.173)	0.000 (0.354)	0.000 (0.011)
First-order control variables	Y	Y	Y	Y
Second-order control variables	Y	Y	Y	Y
Time fixation effect	Y	Y	Y	Y
Regional fixed effect	Y	Y	Y	Y
Sample size	572	2808	2015	1365

6.1.2. Economic development status

With the continuous strengthening of environmental supervision, the behavior pattern of local governments in implementing the central environmental protection policies has shifted from widespread non-compliance to a coexistence of "race to the bottom" and "race to the top". This transformation has directly led to significant differences in environmental governance strategies among regions, especially between economically developed and underdeveloped areas, as well as

between regions with advanced and underdeveloped digital finance. Specifically, economically and digitally finance advanced regions tend to adopt more proactive governance strategies, aiming to gain a first-mover advantage through optimized governance; while economically and digitally finance underdeveloped regions are more likely to adopt a passive waiting strategy, waiting for changes in external conditions or policy directions. First, based on the median of per capita GDP, the samples are divided into economically underdeveloped and economically developed regions, as shown in models (1) and (2) of Table 7. The coefficient of the impact of green finance policies on the green finance development of non-pilot cities adjacent to economically developed regions is positive and passes the significance test at the 1% level, but the impact on the green finance development of non-pilot cities adjacent to economically underdeveloped regions is significantly negative. Second, based on the digital finance index, the samples are divided into financially underdeveloped and financially developed regions, as shown in Models (3) and (4) of Table 7. The coefficient of the impact of green finance policies on the green finance development of non-pilot cities adjacent to digitally finance developed regions is 0.013, and it passes the significance test at the 1% level, but the impact on digitally finance underdeveloped regions is significantly negative. The research results show that the impact of green finance policies on the green finance development of adjacent non-pilot cities in terms of economic development and digital finance development is significantly different: its promoting effect is more significant in regions with a better economic foundation and a higher level of digital finance development, while it has an inhibitory effect in relatively lagging regions.

Table 7

Heterogeneity Test Results 2

Variables	(1)Economically Underdeveloped Regions	(2)Economically Developed Regions	(3)Regions with Underdeveloped Digital Finance	(4)Regions with Developed Digital Finance
<i>peerdid</i>	-0.007* (-1.939)	0.019*** (5.066)	-0.007* (-1.692)	0.013*** (3.290)
cons	0.000 (0.078)	0.000 (0.268)	0.000 (0.311)	-0.000 (-0.057)
First-order control variables	Y	Y	Y	Y
Second-order control variables	Y	Y	Y	Y
Time fixed effects	Y	Y	Y	Y
Regional fixed effects	Y	Y	Y	Y
Sample size	1690	1690	1690	1690

6.2. Mechanism Analysis

Under the framework of decentralized governance in China, the competition mechanism

based on the "promotion competition" theory, which is a benchmark for performance competition, drives local officials to compete for scarce promotion opportunities by establishing horizontal comparative advantages in performance. When the density of green finance pilot programs in adjacent regions increases, a multi-dimensional performance assessment system forms regional policy pressure signals, which drive the learning effect of institutional adaptation in adjacent non-pilot cities. Particularly, the demonstration gap of pilot cities triggers the imitation mechanism of environmental regulations, under the pressure of institutional isomorphism, adjacent non-pilot cities reconstruct the legitimacy of regional governance through policy transplantation. This spatial knowledge spillover effect ultimately propagates to the dimension of green finance development. Therefore, this paper adopts the research method of Tian and Liu (2021) for empirical analysis. First, two methods are used to evaluate the number of pilot cities within provinces: calculating the number of pilot cities within the province, denoted as cities; as shown in Model (1) in Table 8. The result shows that the coefficient of cities*peerdid is 0.013, and it passes the significance test at the 1% level, indicating that the increase in the number of green finance policy pilot cities within provinces can promote the development of green finance in adjacent non-pilot cities. This reflects that the increase in the number of pilot cities, through the pressure mechanism of the system, can effectively drive the improvement of green finance development in adjacent non-pilot cities. Second, the average value of green patent applications of all pilot cities within the province (quality) is used as an indicator to measure the environmental quality of pilot cities, as shown in Model (2) in Table 8. The coefficient of quality*peerdid is 0.007, and it passes the significance test at the 1% level, indicating that the environmental quality implementation status of the green finance policy pilot cities has a significant spillover effect on the green finance development of adjacent non-pilot cities through the pressure of the system.

Although the central government has incorporated ecological constraint indicators into the officials' assessment and implemented the "one-vote veto" for environmental protection, under the framework of fiscal decentralization and the promotion competition theory, local governments exhibit a strategic policy implementation equilibrium: they avoid environmental accountability to maintain their promotion competitiveness, while avoiding excessive regulation that would impact the fundamental aspects of economic growth. This "environmental governance threshold effect" leads local governments to pursue merely compliance-based governance rather than Pareto optimality. After all, economic growth still holds an important position in the promotion evaluation. That is, there exists a situation of environmental qualification competition. Local governments in this regard often merely meet the nationally recognized standards and do not actively enhance the governance intensity. When the environmental regulation intensity in adjacent non-pilot cities is relatively weak, to highlight their own environmental advantages, they will be more proactive in fulfilling environmental responsibilities, and the impact on green finance development is more significant; conversely, when the environmental regulation intensity in

adjacent non-pilot cities is relatively strong, the incentive for fulfilling environmental responsibilities is insufficient, and the impact on green finance is relatively smaller. This article measures the level of environmental governance by urban carbon emissions. When the urban carbon emissions are too high, local governments, in order to achieve low-carbon development, will adopt strict environmental governance policies to reduce carbon emissions; while when the urban carbon emissions are low, local governments usually do not take strict environmental governance measures to pursue better environmental quality, in order not to have adverse effects on economic development. This article uses the median as the threshold, setting cities with carbon emissions lower or equal to the median as 1, and otherwise as 0, this is the weak environmental governance group; setting cities with carbon emissions higher than the median as 1, and otherwise as 0, this is the strong environmental governance group. The regression results are shown in Table 5. The result shows that the $gtpf*peerdid$ coefficient is 0.048, and it passes the significance test at the 1% level, indicating that the policy shock significantly drives the green finance development of the strong environmental governance group in adjacent non-pilot cities; but the $dtpf*peerdid$ coefficient is significantly negative. This reflects that when the carbon emissions in adjacent non-pilot cities are too high, the incentive effect on adjacent non-pilot cities is stronger, and such cities are more inclined to implement strict environmental governance policies, which leads to better development effects on the green finance of such cities; while when the carbon emissions in adjacent non-pilot cities are relatively small, it inhibits the influence on adjacent non-pilot cities, and is less likely to have a positive effect on the green finance development of such cities. This result reflects that officials neither ignore the severity of environmental governance nor strictly enforce environmental governance policies.

Table 8

Mechanism Analysis

Variable	(1) <i>gfi</i>	(2) <i>gfi</i>	(3) <i>gfi</i>	(4) <i>gfi</i>
<i>cities*peerdid</i>	0.013*** (2.967)			
<i>quality*peerdid</i>		0.007*** (3.916)		
<i>dtpf*peerdid</i>			-0.034*** (-4.533)	
<i>gtpf*peerdid</i>				0.048*** (5.752)
cons	0.000 (0.518)	0.000 (0.480)	0.000 (0.584)	0.000 (0.685)
First-order control variables	Y	Y	Y	Y
Second-order control variables	Y	Y	Y	Y

Time fixed effects	Y	Y	Y	Y
Regional fixed effects	Y	Y	Y	Y
Sample size	3380	3380	3380	3380

7. Results Discussion

Based on the existing literature, this paper delves deeply into the impact of green finance policies on non-pilot cities, particularly examining whether green finance policies have driven the development of green finance in adjacent non-pilot cities. Previous studies have mainly focused on the green, economic and environmental benefits of pilot cities for green finance policies, and there is a significant gap in understanding the driving effect on their adjacent non-pilot cities. Our research aims to bridge this gap by providing empirical evidence to reveal the demonstration and driving effects of green finance policies on green finance in both pilot and non-pilot cities.

First of all, this research contributing to the spatio-temporal evolution of green financial development, studies have shown that green was unbalanced in spatial distribution and financial development level and the polarization of remarkable differences problem; The level of green finance development in economically developed cities is generally higher than that in less developed cities. The development of green finance in high-level and high-standard cities shows an evolutionary feature of first expanding and diverging, then contracting and aggregating.

Secondly, the research in this paper shows that green finance policies have a demonstration effect on the development of green finance in pilot cities, and at the same time, green finance policies have a driving effect on the development of green finance in adjacent non-pilot cities. Interestingly, compared with non-adjacent non-pilot cities, green finance policies have increased the development of green finance in adjacent non-pilot cities by 0.5%. This study further expands their research findings and provides empirical evidence that green finance policies have also driven the development of green finance in adjacent non-pilot cities, which also confirms the spillover effects of policies on non-pilot cities.

Furthermore, the heterogeneity analysis in this paper indicates that green finance policies have a positive impact on the development of green finance in non-pilot cities adjacent to large cities, but the impact on medium and small cities is not significant. Part of the reason is that non-pilot cities adjacent to big cities are often closely linked to the industries of big cities and may have taken on some of the green industries or environmental protection projects of big cities, thus

709 having a higher demand for green finance. However, the industrial foundation of medium and
710 small-sized cities is relatively weak, the scale of green industry development is small, and their
711 demand and capacity to undertake green finance are limited. Similarly, green finance policies have
712 played a positive role in the development of green finance in non-resource-based neighboring
713 non-pilot cities, but have not had a significant effect on resource-based cities. Some possible
714 reasons are the reliance on traditional resource-based industries such as coal, steel and non-ferrous
715 metals, with a single industrial structure and a weak foundation for green transformation.
716 Although green finance policies encourage green projects, these cities find it difficult to break
717 away from their reliance on traditional industries in the short term. The insufficient reserve of
718 green projects leads to an insignificant policy effect. Green finance policies have had a positive
719 driving effect on the development of green finance in non-pilot cities adjacent to economically and
720 digitally developed regions, while interestingly, they have had a negative impact on economically
721 and digitally underdeveloped regions. Part of the reason is that in regions with a solid economic
722 and digital finance foundation, after the implementation of green finance policies, it is easier to
723 attract the aggregation of green capital, talents, technologies and other elements, forming a
724 "positive feedback" mechanism. Neighboring non-pilot cities can indirectly enjoy policy
725 dividends through industrial synergy, capital flow, and technology spillover with developed
726 regions. Due to the weak digital financial infrastructure and insufficient reserves of green projects,
727 after the implementation of green finance policies, it may instead lead to the flow of scarce local
728 funds, talents and other elements to developed regions or pilot cities, creating a "siphon effect",
729 intensifying the difficulties in the development of local green finance and having a negative
730 impact.

731 Finally, the mechanism analysis in this paper indicates that the increase in the number of pilot
732 cities for green finance policies within a province and the better the implementation of
733 environmental quality in these pilot cities themselves can drive the development of green finance
734 in adjacent non-pilot cities. The policy shock has significantly driven the development of green
735 finance in the strong environmental governance group of neighboring non-pilot cities.
736 Interestingly, when the carbon emissions of neighboring non-pilot cities are relatively small, it has
737 inhibited the development of green finance in these cities. One possible reason is that high-carbon
738 emission cities face stronger "accountability pressure". Cities with high carbon emissions are more

likely to attract the attention of higher-level governments, the media and the public, and become the key targets of environmental protection inspections, patrols and audits. Therefore, green finance has become a carrier of "political signals". Even if it is not a pilot city, it will proactively "step up" its implementation, forming a policy "spillover effect". However, low-carbon emission cities lack "executive motivation". Cities with low carbon emissions themselves have less environmental pressure, are not included in the key supervision list, have weak political incentives, and the "attention" from higher authorities to their green transformation is low. Meanwhile, these cities often have a small reserve of green projects and a weak foundation in the green industry. Even if they want to develop green finance, they still face the predicament of "no projects to invest in".

8. Conclusions and Policy Recommendations

Based on the panel data of 269 cities in China from 2011 to 2023, this paper employs fixed-effect models, dual machine learning models and other methods to examine the impact of green finance policies on green finance in adjacent non-pilot cities, and conducts in-depth research on their heterogeneity and mechanism of action.

The main conclusions are as follows: (1) Green finance policies have a demonstration effect on the impact of green finance in pilot cities; Green finance policies can drive the development of green finance in adjacent non-pilot cities and have passed robustness tests such as replacing explanatory variables and tailing treatment, providing data support for further promoting the development of green finance through regional linkage between green finance policy pilot cities and adjacent non-pilot cities. (2) Green finance policies in non-resource cities, large cities, economically developed regions and regions with advanced digital finance can have a positive effect on the green finance of adjacent non-pilot cities. The impact on medium and small cities and resource-based cities is not significant, while the impact on economically developed regions and regions with advanced digital finance is significantly negative. (3) The more pilot cities for green finance policies there are, the more it can stimulate the development of green finance in neighboring non-pilot cities within a province. The institutional pressure brought about by the implementation of environmental quality in the pilot cities of green finance policies themselves has a significant demonstration and driving effect on the development of green finance in adjacent non-pilot cities. The environmental quality of green finance policies can motivate the development

of green finance in neighboring non-pilot cities. However, this effect can only encourage local governments to hold environmental protection qualification competitions and cannot promote further strictening of environmental governance in neighboring non-pilot cities. Based on the above conclusions, this paper puts forward the following policy suggestions:

First, strengthen pilot demonstrations and build a collaborative empowerment mechanism. A comprehensive review of the experiences of pilot cities should be conducted, a collaborative and interactive mechanism of "government-financial institutions-market entities" should be established, policy coordination should be strengthened, the standard system should be improved, and the risk control capacity should be enhanced. Focus on building a green finance innovation demonstration zone, establish a gradient support system covering the transformation of traditional industries and the cultivation of emerging green industries, and promote the transformation of traditional industries towards green, low-carbon and intelligent development through policies. Improve the application of new tools such as the securitization of green technology patents, enhance the overall competitiveness and sustainability of the industry, and cultivate new green financial drivers that are in line with the development of Chinese-style modernization.

Second, strengthen cross-domain collaboration platforms and innovate regional radiation and transmission paths. Strengthen policy coordination and regional cooperation, improve the green finance policy system, promote innovation in green finance products and services, enhance the capacity for green finance risk management, and strengthen the cultivation and introduction of green finance talents. For instance, neighboring non-pilot cities should establish a green finance cooperation mechanism with pilot cities and jointly formulate green finance development goals and plans. Establish a cross-regional green finance cooperation platform to promote information sharing and experience exchange between pilot cities and adjacent non-pilot cities.

Third, strengthen green finance and adopt classified measures based on local conditions. First, non-resource-based cities, large cities, and regions with developed economies and digital finance should enhance regional green finance cooperation, play a radiating and driving role, and promote the development of green finance in neighboring cities through policy guidance and resource sharing. Second, small and medium-sized cities and resource-based cities should, in light of their own characteristics, explore suitable green finance development models, strengthen infrastructure construction, enhance the level of digital finance, and boost the internal driving force for the

development of green finance. Third, regions with developed economies and digital finance need to pay attention to the potential negative impacts of policy spillover, optimize green finance policies, avoid adverse competition for neighboring cities, and promote the coordinated development of regional green finance.

Fourth, optimize the spatial layout of the pilot program and develop a cross-regional ecological compensation market. Priority should be given to establishing additional pilot zones in areas with weak environmental governance within the province, and a "strong pilot-weak non-pilot" pairing mechanism should be formulated to enhance the transmission of institutional pressure from high-implementation pilot projects to neighboring cities. Establish a cross-city trading platform for carbon emission rights and pollutant discharge rights within the province, allowing non-pilot cities to obtain quota benefits by undertaking pilot environmental governance projects, and transform the qualification competition into substantive governance cooperation. Set up a special assessment of environmental governance progress rate, weaken the ranking of absolute indicators, and add an assessment indicator of cross-regional coordinated emission reduction volume to break the ceiling effect of governance.

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